1994

Comparison of Preparation in Simulated Curved Canals Using Two Types of Nickel-Titanium Instruments and Hand Instrumentation

Mary Ann Ellenz Campbell
Loyola University Chicago

COMPARISON OF PREPARATION IN SIMULATED CURVED CANALS USING TWO TYPES OF NICKEL-TITANIUM INSTRUMENTS AND HAND INSTRUMENTATION

BY

MARY ANN ELLENZ CAMPBELL, B.S., D.D.S.

A Thesis Submitted to the Faculty of the Graduate School of Loyola University of Chicago in Partial Fulfillment of the Requirements for the Degree of Master of Science

January

1994

DEDICATION

I dedicate this thesis to the late John V. Madonia, D.D.S., Ph.D., affectionately known to his students as "Doc." Dr. Madonia was instrumental in advancing my dental career. He was not only a teacher but a dear family friend whose unfortunate and untimely death has left a void in the lives of all those he has touched. His untiring enthusiasm, his resolute devotion to his profession, and his loving concern for others will be an inspiration and motivation for all who cherish his memory.

ACKNOWLEDGMENTS

I owe a debt of gratitude to several individuals who have helped me throughout my studies at Loyola. I wish to extend a special thank you to Dr. Franklin Weine, under whom it has been a privilege to study. Not only do I value his direction as a mentor and advisor but also, regard him as a close personal friend.

To Dr. Jerome Pisano, I express my sincere thanks for his advice and his very willing assistance in the completion of this thesis as well as his guidance throughout my endodontic residency.

To Dr. James Sandrik, I greatly appreciate his support in this project. I have yet to meet another professor who could make stone, plaster, and compound more interesting.

I further acknowledge Dr. Beth Sheridan and Dr. Leo Lazare, with whom I had the pleasure of spending my two years of endodontic training. I am certain we will remain lifelong friends.

To my family, who was always there providing love, assistance and encouragement, I am genuinely grateful. Finally, my most heartfelt gratitude goes out to my husband, Kevin, whose unlimited love and support has made the completion of my graduate studies and this thesis a reality.

VITA

The author, Dr. Mary Ann Ellenz Campbell, was born in La Crosse, Wisconsin on the tenth of September, 1958.

In the fall of 1976, she entered the University of Wisconsin at La Crosse, for a year of basic studies. In 1977, she transferred to Marquette University in Milwaukee, Wisconsin, majoring in dental hygiene. She received a Bachelor of Science degree in June, 1981.

Following graduation from Marquette University, she returned to La Crosse, Wisconsin where she practiced dental hygiene until August, 1983.

She continued her dental education at Loyola University School of Dentistry in September of 1983, and graduated in May of 1987, receiving the degree of Doctor of Dental Surgery.

In July of 1988, she completed a general practice residency at Meriter/Madison General Hospital in Madison, Wisconsin.

Upon completion of her general practice training, she moved to Milwaukee, Wisconsin and became an associate dentist with Elmbrook General Dentistry. In addition, she served as an associate clinical professor in the department of Periodontics at Marquette University School of

Dentistry.

In August of 1989, she returned to the Loyola University School of Dentistry and began a dual course of study leading to the Degree of Master of Science in Oral Biology and a Certificate of Specialty Training in Endodontics.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF ILLUSTRATIONS

INTRODUCTION

It has been well established throughout the history of the practice of endodontics that canal preparation is the most important phase of therapy. Too often, however, more emphasis is placed on the method of canal filling rather than proper debridement. When a canal is prepared properly, any of the accepted methods of filling will almost certainly produce a successful result (1). The purpose of canal preparation is thorough debridement while enlarging the canal yet maintaining its original shape. If these objectives are met and combined with appropriate obturation procedures, the success of treatment is generally ensured.

Inevitably, this essential preparation phase is also the most difficult, tedious, and time consuming portion of therapy. The complex configurations of root canals, especially curved canals, present a particular challenge to the principles of preparation. While straighter canals, such as those commonly found in anterior teeth, are easily prepared with traditional intracanal instruments, these same instruments will not, as readily, negotiate curved canals. Consequently, a myriad of alternate file types, instrumentation techniques, automated handpieces, sonics, ultrasonics and combinations thereof have been developed.

Adaptation of general preparation principles for use in curved canals, such as pre-curving files and/or clipping files and removing flutes as proposed by Weine (1,2), in addition to the use of files with designs modified to improve flexibility, have, indeed, enhanced canal preparation. However, claims to increase efficiency and increase predictability of instrumentation with the use of automated devices have gone unfounded. So far automated techniques have not been proven to be superior or more effective than hand instrumentation (3).

Since the conversion from carbon steel in the 1960's, stainless steel has been the material of choice for the fabrication of endodontic instruments. Recently, a nickel-titanium alloy, a frequent component of orthodontic wire, has been introduced for use in endodontics. Instruments fabricated from this nickel-titanium alloy seem to exhibit properties imparting increased flexibility. Nickel-titanium possesses a very low modulus of elasticity (modulus of elasticity connotes rigidity or stiffness thus a lower value indicates increased flexibility) (4). Nickel-titanium endodontic files are now being developed and introduced for hand instrumentation. McSpadden has also developed a nickel-titanium (Ni-Ti) file design appropriate for use in a rotary handpiece.

The purpose of this study is to evaluate and compare three methods of canal preparation in curved canals (30 degrees): conventional hand instrumentation utilizing stainless steel files of flexible design, hand instrumentation with Ni-Ti files and instrumentation with a NT-matic handpiece and its corresponding Ni-Ti files.

REVIEW OF THE LITERATURE

Canal preparation

In 1961, Dr. John Ingle presented a paper at the American Association of Endodontists annual meeting, citing causes of failures in endodontic therapy. Though he deemed only 5.55 percent of over a thousand cases as failures, an overwhelming majority were due to some error in preparation. Incomplete obturation of the root canal was reported as the primary cause of failure. The second greatest cause of failure was root perforation during instrumentation. Although it would appear that poor root obturation is the prime factor in case failure, Ingle maintained the problem is really more encompassing than it appeared. In those cases where obturation was unsatisfactory, the canal was also incompletely debrided. Ingle, therefore, concluded that total obturation is really dependent upon careful coronal and radicular cavity preparation in addition to proper case selection and the correct use of filling materials (5,6). Similarly, Heuer (1963) stated that success in endodontic therapy is unrelated to the type of intraradicular medication used, to whether bacteriologic controls are employed, or even to what materials or methods are employed in filling the root canal, provided that the biomechanical considerations of thorough root canal preparation and hermetic sealing of the root apex have been met (6).

In 1967, Carl Haga conducted a study to determine the adequacy of root canal instrumentation. Haga likened the importance of root canal preparation to that of cavity preparation in operative dentistry, such that the restoration will only be as good as the cavity preparation (7).

According to Schilder, the ideal preparation of the root canal to receive a gutta-percha filling should result in a continuously tapering conical form that follows the plane of the original canal without altering the position of the apical foramen (8). In 1975, Weine, Kelly and Lio studied the effects of preparation procedures on original shape. Through the use of simulated canals in clear-casting resin blocks, they were able to demonstrate that as a consequence of instrumentation in curved canals, files tended to engage the inner wall in the coronal portion of the canal and the outer wall near the apex. This resulted in an hourglass shape in the apical one third. The authors labelled the wider irregular area near the apex as the "zip" and the site where the canal was narrowest as the "elbow." A flared preparation was recommended using a rasping action and which included clipping the tips of files to make intermediate sizes plus removal of the outer edge of flutes on these tip-prepared files (2). Mullaney (1979) also addressed the difficulties encountered during instrumentation. He described three types of deviations from the original curvature of the canal that may occur at the apex. First, perforation results when too large a file is used, perforating the root surface at a point other than the anatomic apical foremen. The creation of a ledge, or the formation of a new canal tangentially to the original that has not perforated the root is another common deviation. A third common iatrogenic deviation is the formation of the "zip," as previously described (9).

Allision, Weber and Walton (1979) sought to evaluate the effect of canal preparation on the quality of apical and/or coronal seal. Canals in extracted teeth were prepared with a standardized taper or a step-back flared taper and obturated. The quality of the seal was determined by the amount of leakage of an isotope (Ca 45) around the obturating materials into the canal as assessed by autoradiography. Standardized preparations generally showed extensive leakage apically whereas step-back preparations showed little, if any, leakage. Microleakage usually extended close to the level of spreader tip penetration. Coronal sections did not show significant microleakage (10).

Lim and Webber (1985) carried out a study to examine the effect of the step-back enlargement technique on the shape of the curved root canal. Radiographs were taken of extracted teeth before preparation. Photographic prints obtained from the radiographs were used to make superimposed tracings of the teeth before preparation, after apical preparation and after coronal flaring. After apical preparation, the root canal sometimes demonstrated an hour-glass shape. This appearance was more commonly observed when root canals of greater curvature were prepared. Flaring the coronal portion of the canal was often successful in enlarging the narrowest portion or the elbow of this hour-glass shape (11). Step-back preparations continue to remain the standard to which other instrumentation techniques are compared.

Preparation Comparing Mechanical Handpieces and Hand Instrumentation

A variety of automated endodontics handpieces have been developed in an effort to minimize operator fatigue and lengthy preparation times often associated with conventional instrumentation. Most mechanical devices are designed to transform a continuous rotary motion in the handpiece motor to either an alternating quarter turn movement or to a combination of longitudinal and quarter turn movements. The main purpose of most of these handpieces is to reproduce the basic motions of manual instrumentation (12).

One of the first engine-driven handpieces was the Giromatic, introduced in 1964. The Giromatic is a right angle handpiece which holds a barbed broach or a file rotating a quarter turn. In 1967, Frank presented his empirical analysis of the Giromatic. While reluctant to recommend its use as the sole instrument in preparation, Frank did suggest incorporation of the technique as an adjunct to canal enlargement if sound endodontic principles were maintained (13).

Harty and Stock (1974) conducted one of the first published studies comparing the effectiveness of the Giromatic system with that of hand operated instruments. The mesial roots of extracted mandibular molars were prepared either by a standardized technique with the Zipperer Hedstrom file or with the Giromatic handpiece. Their results indicated that there was no difference between the systems. They concluded that neither was adequate for the ideal mechanical preparation of the selected canals. However, Harty and Stock described their ideal preparation as one which was round in cross section in the apical fifth of the root (14).

In 1975, O'Connell and Brayton compared the preparation of extracted teeth by the Giromatic and the W&H (another contra-angle handpiece) with conventional instrumentation. Evaluations were made using a silicone injection of the prepared canals. Conventional hand instrumentation proved to be superior and required approximately the same amount of time as automated instrumentation (15). Hoping to achieve the same "ideal" preparation as Harty and Stock, Jungmann, Uchin and Bucher (1975) studied the ability of four common instrumentation techniques to produce a round apical preparation. Filing and reaming with a K-type file and reaming with a reamer were compared with the Giromatic reamer. It was concluded that no technique will predictably produce a round preparation in the apical portion. Filing action with a K-type file provided the least round preparation (16).

The effectiveness of removing tissue debris from the root canal was evaluated by Klayman and Brilliant in 1975. Mesial roots of extracted mandibular molars were prepared with either the Giromatic or by serial (step-back) preparation. The serial preparation removed significantly more tissue from canals than the Giromatic (17). Subsequently, Weine, Kelly and Bray (1976) compared the Giromatic and the W&H with hand instrumentation by reaming and with filing while removing flutes plus flaring. Again, their study used simulated curved canals in resin blocks. Canal preparation by reaming required the least amount of time. However, reaming action and canals prepared with the automated handpieces demonstrated a considerably wider zip (18).

Abou-Rass and Jastrab (1982) used Gates-Glidden drills and Peeso reamers to flare canals prepared by hand. The addition of these auxiliary aids compared quite favorably to hand instrumentation alone, decreasing operator time, and increasing the overall quality of preparation. The Giromatic method required the least performance time but produced the most procedural errors, including apical perforations, ledges and debris packing (19). Lehman and Gerstein (1982) evaluated two other mechanized devices, the Union Broach Endo Angle (alternate quarter-turn rotating movement) and the Kerr Endolift (up and down motion with a slight turning motion). Comparisons were made between hand instrumentation with preflaring and step-back, and the Giromatic. The study included both simulated canals in resin blocks and extracted teeth. Hand instrumentation was the most rapid method and proved better and safer, resulting in the least amount of elliptication (zipping) of the apical third, compared with preparations by the engine-driven devices. When slow speeds were used with the automated handpieces and care taken to keep the working length constant, acceptable, though less than ideal preparations were produced (20).

Spyropoulos, Eldeeb, and Messer (1987) prepared two hundred simulated, curved canals with five different instruments. Three were hand files (Unifile, Trio-Cut, Hedstrom) with the other two (Dynatrak and Giro) being used in a Giromatic handpiece. By comparing differences in diameter of the prepared canals at various levels, hand instrumentation produced a more coronally flared preparation than the Giromatic and the latter frequently produced preparations which lacked taper. When apical diameters were compared, the Giromatic demonstrated a wider or more ellipticated preparation. Hedstrom files showed the best ability for flaring (21). The Societe Endo Technic (SET), another engine-driven handpiece, was studied by Goldman, Sakurai, Kronman and Tenca in 1987. The authors speculated that the rotating motion generated by engine-driven instruments, such as the Giromatic is, the cause of the procedural errors encountered in curved canals. The SET contra-angle is designed to move a file only in an up and down motion. Additionally, the instrument possesses a clutch action which allows the file to stop when too great a resistance is met, to guard against the creation of a "false" canal. The study compared conventional hand instrumentation with the SET in the preparation of the curved roots of extracted molars. While both procedures did straighten canals, preparation with the SET maintained the original pathway more closely than did hand instrumentation (22).

In 1989, Ianno and Weine conducted a final study comparing the Giromatic with the Kerr M-4 (alternate quarter-turn horizontal motion). The Giromatic handpiece utilized files included in the unit, while the M-4 used Kerr K-flex files. Simulated curved canals were instrumented and evaluated for differences in preparation. The Giromatic was more consistent in maintaining original canal shape, removing debris and gaining coronal flaring. However, both systems produced ledges and canal distortions (23).

Recently, Walton stated that most instruments are poorly designed for their intended use. He added that further confusion arises because manufacturers continually introduce new designs with unsubstantiated claims of superiority. What is most important is not how the instruments are designed but how they are used. Furthermore, the considerable amount of excitment and interest generated by these new automated devices has not been justified by their demonstrated benefits. Automated techniques have not been shown to be superior or more efficient than standard hand techniques. If dentists are unable to properly clean, shape, and obturate canals using commonly taught and practiced techniques, they will be unable to do so with the devices (3).

Physical and Mechanical Properties of Endodontic Instruments

When selecting an endodontic instrument, its physical and mechanical properties must be evaluated. Early root canal instruments were fabricated from carbon steel. In 1962, Craig and Peyton conducted an investigation of the physical properties of carbon steel root canal files and reamers. Their purpose was to measure the resistance to permanent bending, fracture during bending, and breakage during twisting. Employing stiffness tests (amount of angular deflection after bending), cold bend tests (resistance to fracture of the instrument as a result of successive 90 degree bends) and torque tests (resistance of the instrument to breakage by twisting), the following conclusions were reached: there was a gradual increase in stiffness with increase in instrument size; cold bend and torque tests established the fact that larger instruments were less resistant to breakage by bending or twisting than smaller instruments. Large instruments were defined as a conventional no.4 and up or a standardized 35 and up. The tests indicated that root canal files and reamers should be bent as little as possible. The authors suggested that special care should be taken to avoid twisting large size instruments (24).

Stainless steel root canal instruments were soon introduced, having the advantage of being more resistant to corrosion than carbon steel instruments. This property allowed reamers and files to be sterilized by steam autoclaving as well as by dry heat. In a subsequent study, Craig and Peyton (1963) compared the physical and mechanical properties of these "new" stainless steel instruments with those of carbon steel instruments. The same testing procedures were followed as in the previous study. The stainless steel instruments compared favorably to carbon steel. The standardized stainless steel files and reamers were considerably more flexible than carbon steel instruments of the same size. The difference corresponded to approximately one instrument size. The increase in flexibility was directly attributed to the differences in materials. The resistance to fracture by bending was slightly higher for the stainless steel instrument than for the carbon steel. Torque resistance between stainless and carbon steel files was similar, however the torque resistance of the smaller stainless steel reamers was greater than that of the comparable carbon steel reamers. Additionally, no difference in the ability of the instruments to file dentin walls was reported. The authors concluded that the stainless steel instruments held considerable promise for endodontic procedures. The suggestion was also made, that due to their improved resistance to corrosion and the apparent toleration of tissues to stainless steel, in certain cases these instruments may show promise as obturators (25).

Oliet and Sorin (1965) listed some of the ideal characteristics of endodontic instruments. These included good cutting shape, uniform and consistent dimensional characteristics, hardness to resist distortion and wear, resilience to avoid fracture and a good fatigue life. Because some of these characteristics are diametrically opposed, they suggested that the optimum instrument must represent a balanced compromise of various physical properties. The problem then becomes one of determining and evaluating these characteristics as they exist in available instruments. The intent of their study was to test the torsional properties measured on an instrument from the onset of initial stress to the point of fracture. This differed from previous studies where torsional properties were related primarily to tests of fatigue. Equipment suitable for performing such a test was designed for this study with reamers being the only instruments tested. Preliminary data suggested that instruments with high torsional strength would withstand considerable distortion before breaking, whereas instruments of lower strength would often break after relatively little twisting. The authors advised, however, that due to the inductive nature of the work no conclusions should be drawn (26).

Craig, McIlwain, and Peyton (1968) continued to investigate the properties of endodontic instruments. Specifically, they evaluated the bending and torsional properties of root canal files and reamers. A new method with improved accuracy for small instruments and that permitted the measurement of both bending and torsional properties was used. As in their prior studies, carbon and stainless steel files and reamers were tested. It was observed that the stiffness of the reamers was lower by at least one instrument size than the stiffness of corresponding files. This difference resulted from the square configuration of the files and the triangular configuration of the reamers. Stainless steel instruments again exhibited lower stiffness values than their carbon steel counterparts, the difference approaching a half an instrument size. The stiffness curves also showed that the smaller the instrument, the more it could be bent before permanent deformation resulted. Maximum torsional deflection showed that the larger instruments fractured at lower values than the smaller instruments and that square instruments fractured at lower values than triangular instruments. Torsion values for stainless steel files were consistently higher prior to breakage than for the carbon steel files. No difference was observed in reamers. An inherently more ductile material than carbon steel, stainless steel was considered to have apparent advantages for clinical use (27).

Chernick, Jacobs, Lautenschlager and Heuer (1976) sought to subject test files to conditions more closely encountered in clinical settings. Particularly, they questioned whether the random though unfortunate fracture of a intracanal instrument is due to inadvertent clinical misuse or to inherent flaws in the instrument itself. Using a modified version of the torsional tester proposed by Oliet and Sorin (1965) the following variables were tested: Clockwise and counterclockwise torsional strength and ductility, the effect of hot bead sterilization, strain-rate sensitivity, and torsional fracture mode. The instruments selected for testing were files being used at the Northwestern University dental clinic. These files were described as stainless steel but actually consisted of a carbon steel core with stainless steel plating for anticorrosive properties and tissue tolerance. If a file is to be used with a rotating or reaming action it will generally be turned in a clockwise fashion, however, there may be an occasion to use a instrument in a counterclockwise manner. Indeed, the authors found the results of the counterclockwise torsion tests most interesting. Torsional tests and SEM examination showed that files twisted in a counterclockwise motion were extremely brittle in comparison with those twisted in a clockwise manner. It was speculated that this phenomenon may be a consequence of the twisting procedures used in fabrication. Endodontic instruments are made from rectangular or triangular wire blanks that have been ground to the proper taper and twisted counterclockwise to produce either a file or a reamer. Perhaps the twisting procedure locks in residual stresses that act to decrease the instrument's ductility in counterclockwise torsion. This effect would probably be more pronounced in files, which are twisted more tightly than reamers. Because the authors suspected that recurrent high temperatures could change the temper of a instrument, the effect of hot bead sterilization was investigated. Bead sterilization at 425 degrees Fahrenheit was found to have no apparent effect on torsional strength and ductility. The results of the strain rate sensitivity tests demonstrated that the rate of clinical torque application will not affect strength and ductility. Finally, the efficacy of plating stainless steel over carbon steel was questioned following this study. SEM studies revealed a tendency of the plating to break away from the core, possibly resulting in the lodging of metal chips in the canal, in addition to the obvious deleterious effects on the cutting efficiency and corrosion resistance. The manufacture of plated instruments was said to have been discontinued subsequent to this investigation (28). Continuing in this same vein, Lautenschlager, Jacobs, Marshall and Heuer (1977) sought to determine whether other brands of files and reamers showed the same tendency toward brittle failure when placed in counterclockwise torsion. Size 20 stainless steel files and reamers by four manufacturers (Kerr, Unitek, IDT-Oratec, Star) and an experimental group were tested. In addition, selected instruments in sizes 10, 15, 25, 30, and 40 were tested to determine if this phenomena could be observed for instruments in other sizes. The same testing procedures were used as in their previous study. Similar data was gathered, clearly indicating that the instruments tested displayed the same tendency for decreased revolutions to failure in the counterclockwise mode. Two brands (IDT-Oratec and Star) appeared to have more counterclockwise ductility, however, the authors cautioned that improvement in a single parameter does not necessarily mean an overall better instrument. While an ADA specification exists governing acceptable values for clockwise torque, no such specification has been determined for counterclockwise torque values. Since this appears to be a relevant clinical parameter, inclusion of this fact was suggested for future specifications (29).

Consequently, a task force was organized recommending that a more exhaustive study of torsion and angular deflection be conducted. Additionally, the task group decided to expand on earlier testing by studying the effects of both clockwise and counterclockwise direction of twist. A round-robin testing program was developed using six laboratories and five brands of instruments. The results of this study were published by Lentine in 1979. The objectives were two-fold: the first was to determine torque and angular deflection values of files and reamers in order to set minimum ISO specification limits; the second, to compare test results with limits specified in published national standards. The results showed a wide range of values within each brand of instrument as well as between brands. Because overall values reported by different evaluators were consistent, some general conclusions could be reached: torque values for files are different than torque values for reamers when twisted in both the clockwise and counterclockwise direction; file and reamer angular deflection values are higher when instruments are twisted in the clockwise direction as opposed to the counterclockwise direction. Also observed was that the maximum torque and angular deflection values obtained in this study are not totally in agreement with the minimum torque and angular deflection values required in ADA specification no.28 for files and reamers. It was suggested that this new set of values be adopted for use in International Standards (ISO) (30).

Three basic instrument types have traditionally been used for intracanal preparation. The reamer was the original root canal instrument. A reamer is a twisted triangular blank with three cutting angles of 60 degrees each. A file

(K-type) is a twisted square blank which yields an additional cutting edge, each angle being 90 degrees. Hedstrom files have flutes that resemble successively smaller triangles set on one another. Triangular sections are gouged from a round blank shaft producing a sharp cutting edge (1).

The physical properties of these endodontic instruments have been shown to be affected by their particular design. Consequently, properties such as cutting ability and flexibiblity have been enhanced by modifying the cross-sectional shapes and flute designs of traditional instruments.

The influence of flute design on cutting efficiency was evaluated by Felt, Moser and Heuer (1982). Four brands of endodontic files and reamers were evaluated: Union Broach, Premier, Unitek and Star. The instruments were mounted in a contra-angled handpiece, the Giromatic, and bovine bone specimens were used as the cutting medium. The reamer group tested was significantly more efficient than the group of all files tested. This included files and reamers from the same brand. Differences between groups of files and reamers from different brands were generally not significant. The Unitek size 30 file of square cross section was significantly less efficient than the Unitek size 30 file of triangular cross section and also less efficient than all the other brands of size 30 files tested (31).

The K-flex and the Uni-file or S-file represent two modified file designs. A diamond blank was used to develop the K-flex file. The diamond blank provides a sharper edge, since the angle is less than the standard file blank of 90 degrees. The Uni-file has a cross-sectional "S" configuration from a machined blank that yields acute angles for increased sharpness (1). Roth, Gough, Grandich and Walker (1983) evaluated both the K-flex and Uni-file along with conventional file types (Kerr, Union Broach and Unitek K-file) on potential for breakage and relative flexibility. Both properties were compared with the latest proposed International Standards Organization's (ISO) specification no. 28 plus an extended test in excess of ISO standards. In the torque tests all but five instruments met the ISO specification. They were Unitek K files sizes 30 to 50. One instrument, the Unitek K-file size 10, failed the stiffness test. Lowest stiffness values were registered by Kerr K-flex (10, 20, 25), Unifile (15, 45), Unitek (30, 35, 40, 50). Highest stiffness values were recorded by Unitek (10), Union Broach (15, 20, 25), and Kerr K-file (30, 50). Fifty-one instrument fractures occurred - 47 beyond ISO specifications. The Unifile claimed 40 of the fractures. Since the Unifile is created by a machined process similar to the Hedstrom file, the authors contend a more appropriate test would be to apply the test specifications established for Hedstrom files. Under ISO specification no. 57, they believed that the Unifile would have performed quite well (32).

Cutting efficiency of endodontic files again provided the subject for a study by Newman, Brantley and Gerstein (1983). A custom designed apparatus was designed to evaluate seven brands of files. Five recently introduced brands were compared with two traditional K-type files. Brands studied were the Kerr K-file and the Burns Unifile, previously discussed, plus the Star Flex-file - a triangular cross-section with a slight change in metal composition; Unitek - a size #30 triangular file, also with a change in metal composition; and the Whaledent Endex file - a traditional flute design or square file. Cutting efficiency was determined by measuring the depth of cut in a bovine bone specimen after 3-minute periods. The Star Flex-file displayed the greatest cutting ability of the seven brands, while the Kerr K-flex file ranked second. The Kerr K, Whaledent and Unitek brands had similar depths of cut for sizes 20 and 25; in size 30, the Unitek file was superior. The Unifile generally demonstrated the poorest performance, probably due to the fact that it cuts in the withdrawal direction only. It was also observed that smaller instrument sizes made slightly deeper cuts, presumably due to less surface area for resistance. All instruments showed the effects of wear; the depth of the second cut was about one-half that of the initial cut (33).

Seeking a similar objective as Chernick et al (1976), the purpose of Roulet's investigation in 1983 was to evaluate the conditions under which endodontic instruments may fracture. Elaborating on the previous study, the influence of sterilization procedures was expanded to include dry and steam heat autoclaving procedures as well as glass bead sterilization. Correlation with instrument size and type was also recorded. Following sterilization procedures, the instruments were clamped and subjected to a dynamic fracture test - repeated bending until fracture occurred. Instruments tested were Kerr reamers, files and Hedstroms plus Maillefer Flex files, all in sizes 08-30. No clinical relevance was attributed to the effects of sterilization procedures. Nonetheless, differences in file size produced highly significant results, such that thicker instruments fractured before the thinner instruments. The increased elasticity of thinner instruments compared to instruments of larger diameter explained this. Flex files in sizes 08 to 20 demonstrated a resistance to fracture superior to the Kerr instruments (34).

As a sequel to their previous study (1983), Brantley and Gerstein, along with Krupp (1984), continued their investigations into the properties of root canal files. Testing the same seven brands of files, mechanical properties were measured under bending conditions and for both clockwise and counterclockwise torsion loading. Once again, the files evaluated were: Kerr K-flex, Star Flex-file, Burns Unifile, Unitek, Whaledent Endex and two traditional brands, the Kerr and Union Broach K-file. While none of the instrument groups failed the bending test, according to ADA specification no. 28, the Star flex-file displayed the greatest flexibility or lowest resistance to bending. The exception being size #30, in which the Unitek instrument exhibited the lowest resistance to bending. Results of general torsion behavior were similar to the bending tests, the Star instruments exhibited the lowest resistance to twisting. In general, the five newer brands had lower resistance to twisting in sizes #10-25 than the traditional brands, with the resistance increasing in the following order: Star Flex-file, Kerr K-file, Whaledent Endex and Burns Unifile. Again, for size #30, an exception occurred with the Unitek brand ranking first in torsion resistance. As with the bending and clockwise torsion tests, the sizes #10-25 Star and the size #30 Unitek instruments exhibited the lowest resistance to counterclockwise twisting. Interestingly, for all instrument brands and sizes, the counterclockwise twist angle for failure was always much less than that for clockwise torsion. The fact that, for size #30, the Unitek instrument demonstrated increased flexibility was attributed to a switch, by the manufacturer, from a square to triangular cross-section after size #25. Accordingly, the authors maintained that the increased elastic flexibility of the triangular (Star Flex-file and size #30 Unitek) and rhomboidal (Kerr K-flex) cross-sectional files is predictable, compared with the square cross-sectional instruments of the same sizes. This dependence of mechanical properties on cross-sectional shape was in accordance with analyses by previous investigators (35).

Nickel-Titanium

While the literature suggested that mechanical properties of file systems can be affected by alterations in cross-sectional shape, the search for further improvements in endodontic instruments continued.

Similar to developments in endodontics, the introduction of stainless steel proved to be a significant advancement for orthodontics. In 1978, Andreasen and Morrow reported on another progression in orthodontic treatment, namely, the development of Nitinol wire. Nitinol was invented in the early 1960's by William F. Buehler, a research metallurgist at the Naval Ordnance Laboratory in Silver Springs, Maryland. The name Nitinol is an acronym derived from the elements which comprise the alloy, Ni for nickel and Ti for titanium and nol from Naval Ordnance Laboratory. Nitinol has a unique property called "shape memory," in which it returns to or "remembers" its previous shape. In addition, Nitinol exhibits outstanding elasticity. Compared with stainless steel, in normal handling, Nitinol wire is more difficult to deform permanently. It can almost be bent back upon itself without taking a permanent set (Figs. 1 and 2). It is this characteristic that offers the orthodontist a considerable advantage when using preformed arch wires. The physical properties of Nitinol compared with stainless steel are as follows:

Material Property	Nitinol	Stainless steel
Alloy	Nickel,titanium	Iron,chrome,nickel
Ultimate strength	230,000-250,000psi	280,000-300,000psi
Modulus of elasticity	4,800,000 psi	28,500,000 psi

Andreasen et al performed a series of tests on the Nitinol wire making comparisons with stainless steel. When the angle of permanent bend was measured the Nitinol wires had a permanent set, or bend angle, of only 5 degrees while the stainless steel wires had a permanent set of from 39 to 40 degrees or greater. Similarly, in torsion tests Nitinol developed a lower torsional load and lower amount of permanent set than the stainless steel wires. In stored energy comparisons, the stored energy of the Nitinol wire was found to be significantly greater than that of an equivalent stainless steel wire. Stored energy correlates to work available in the wire, a greater stored energy presumes increased clinical efficiency. The final analysis was to determine spring rate of the materials; spring rate is defined as the change in load divided by the change in deflection. The spring rate of stainless steel was found to be approximately twice that of Nitinol. The clinical application for orthodontics would be that the Nitinol wire produces a more constant and continuous force on the teeth than stainless steel wire of equivalent size. In other words, the Nitinol wire may be deflected more without deforming. Some of the limitations of Nitinol were also discussed; most significant to these authors was its resistance to taking a bend, causing the placement of desired bends and loops difficult. Additionally, the authors warned that Nitinol cannot be bent over a sharp edge, although, it feels quite ductile, it will readily break when bent over a sharp edge. Finally, because Nitinol by nature is not a stiff wire, it would not be appropriate for use to stabilize the arch at the completion of orthodontic treatment. It was concluded that, when applied with skill and professional judgment, the Nitinol wire is a valuable addition to the orthodontist's armamentarium (36).

Lopez, Goldberg, and Burstone (1979), went on to further characterize the bending characteristics of Nitinol wire. Again, Nitinol was evaluated in comparison to stainless steel. The wires were tested in three different modes, because it was suggested that a bent wire might not have the same properties as a unbent wire. With respect to bending of straight sections, Nitinol demonstrated superior elastic properties as compared to stainless steel. However, when Nitinol is tested in a direction opposite to a permanent bend, there is a considerable loss of elastic behavior. The magnitude of change associated with testing of stainless steel in different modes was not nearly as large as that of the Nitinol. Nitinol also appeared to experience a time dependent relaxation phenomenon. Increases in permanent deformation were small when samples were held up to 60 minutes, but, when a load was maintained over 48 hours permanent deformation drastically increases. Similarly , if a sample was subjected to repeated bending, permanent deformation doubles in just 60 minutes, implying that repeated bending of the wire should be avoided. The results of this investigation, therefore, suggested that bending, time factors and the cumulative effects of cold working can all have deleterious effects on the elastic characteristics of Nitinol (37).

It was not until 1988, that a published report of an application for Nitinol in endodontics appeared in the literature. Walia, Brantley and Gerstein conducted an initial investigation of a prototypic Nitinol root canal file. The purpose of this study was to explore the feasibility of manufacturing root canal files from Nitinol and to evaluate the bending and torsional properties of these instruments. The files were manufactured from standard preformed Nitinol arch wire blanks, 0.020 inch in diameter, onto which the fluted triangular cross-sectional shape was machined. The experimental files were only fabricated in size #15 and were compared to #15 stainless steel control files manufactured in the same manner. The Nitinol and stainless steel files were evaluated in three mechanical testing modes which were cantilever bending, clockwise torsion and counterclockwise torsion, following the experimental methods previously used by Krupp et al. Results demonstrated that the Nitinol files had considerably greater elastic flexibility than the stainless steel files in all three testing modes. Bending curves indicated that permanent deformation of the 3-mm apical regions of the stainless steel files began at a bend angle of approximately 30 degrees, but that the apical regions of the Nitinol files were undergoing largely elastic deformation even at bend angles of 90 degrees. Even after unloading, very little if any permanent bend was observed. In the clockwise torsion studies, the Nitinol again exhibited considerably greater resistance to fracture. The Nitinol files were capable of under going a mean value of 2-1/2 revolutions before fracturing, while the stainless steel files fractured after a mean value of 1-3/4 revolutions. In counterclockwise torsion, the Nitinol files experienced largely elastic deformation before fracturing at a mean value of 1-1/4 revolutions, while the stainless steel files fractured at a mean value of between 1/2 and 3/4 revolutions. In view of these promising results, the authors suggest that Nitinol endodontic files may have particular promise for the clinical preparation of curved root canals (38).

Only recently have a number of Nitinol endodontic instruments have become available for clinical use, one such instrument is the "MAC" file manufactured by the NT Company. The "MAC" is a machined instrument into which two flute designs are incorporated. On one surface a Hedstrom configuration is present with a K-type shape 180 degrees on the other side, also, there is a diagonal cutting edge at the tip of the file (Figs. 3 and 4).

At the 1993 American Association of Endodontics Fiftieth Annual session, Serene reported on the use of this particular file in the dental clinic of the University of South Carolina. This Nitinol file was initially introduced into the pre-clinical endodontic technique lab. Student acceptance of this instrument was quite favorable and results appeared promising. The students were divided into two groups, one group started out with the Nitinol file and then changed to the conventional K-type file while the second group began with the K-type file and progressed to the Nitinol instrument. In those cases prepared with the conventional instrument 40-50% demonstrated transportation or zipping of the canals, conversely with Nitinol instrumentation transportation was not observed. When the Nitinol prepared technique teeth were sectioned, circular preparations were found, right down the central axis of the canals. Given the choice of what instrument to use in their clinical procedures the students, interestingly, choose to use both conventional and Nitinol files. Better tactile sensation was the advantage attributed to the K-type files, the extreme flexibility of the smaller Nitinol files made positioning of the file into the orifice of the canal difficult. Consequently, the use of sizes 15-40 K-type and

25-50 Nitinol files were put to use in the undergraduate clinic. Additionally, the files could be used in an alternating fashion as a Nitinol file of the same size is slightly smaller than the corresponding K-file, due to the difference in flute design. Following a year of use, of the Nitinol instruments, in the undergraduate clinic, the following observations were made: instrumentation of small curved canals up to a size 40-45 and distal canals to a size 50 is readily accomplished with the Nitinol files; due to the ease of which canals are prepared to final instrument size, the need for preflaring is eliminated; a significant decrease in the number of ledged, perforated, and transported canals had been observed; length of instrumentation time appeared to be decreased by 20-25%, and Nitinol files, in particular, sizes 25 and larger may be used 20-35 times before discarding. Serene, therefore, concluded that the quality of endodontic cases in the undergraduate clinic has significantly improved with the use of the Nitinol instruments (39).

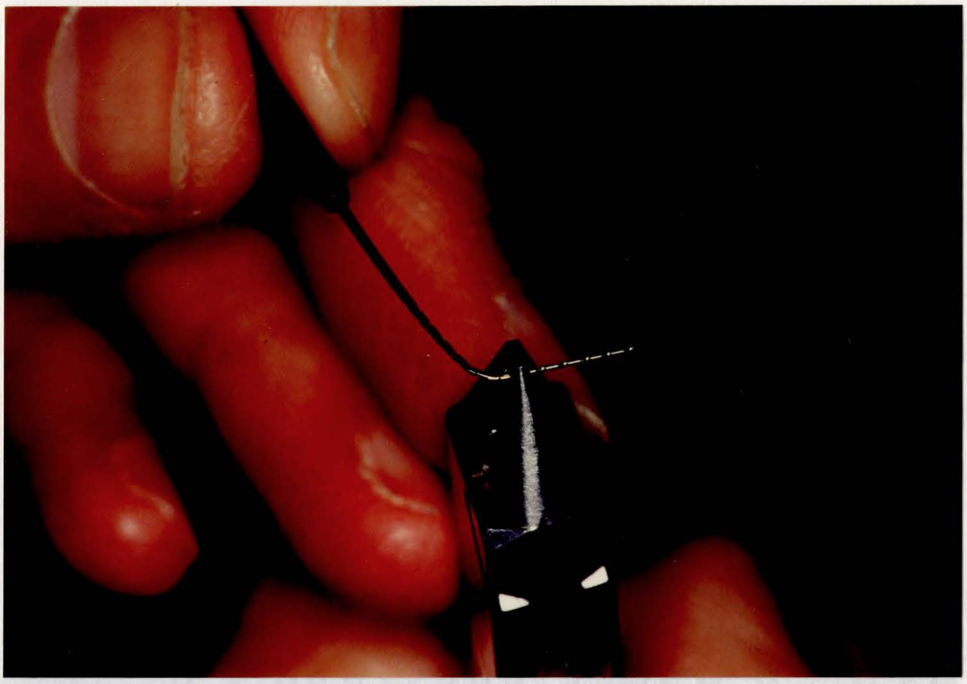


Figure 1: Nitinol file during bending

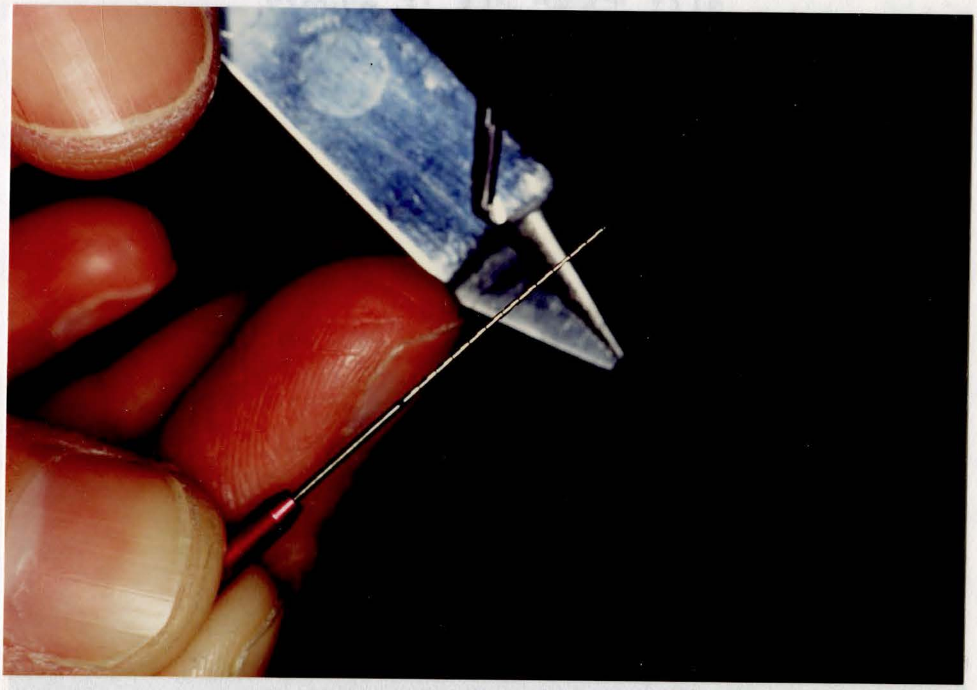


Figure 2: Following bending, Nitinol file resumes its original shape.

Figure 3: #25 "MAC" file

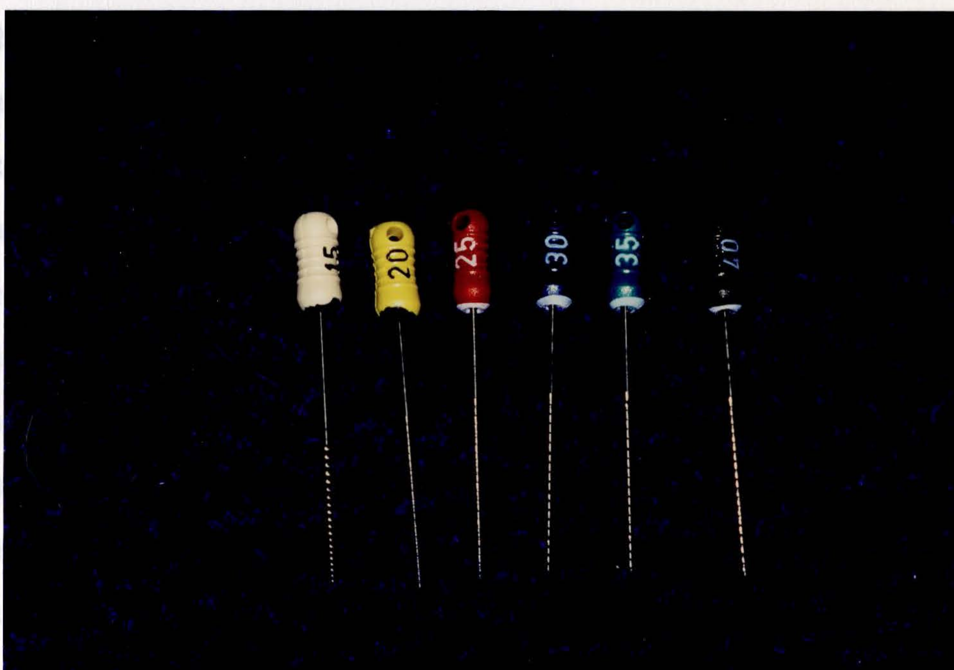


Figure 4: #15-40 "MAC" files

Use of Simulated Curved Canals

Ideally, the effects of preparation on root canal shape should be a study using human teeth. It is difficult, however, to obtain an adequate number of natural teeth which are comparable in shape, size length, hardness and curvature (40). The use of simulated curved canals has been demonstrated to be an acceptable substitute in the assessment of preparation procedures. Several investigations previously mentioned have made use of simulated canals (2, 18, 20, 21, 23).

One of Weine, Kelly, and Lio's objectives, of their 1975 preparation study, was to create a simulated canal in a completely transparent system that would provide a vehicle for complete visualization of all the intracanal procedures as they were performed. Silver cones were shaped with a gradual curve simulating the type of curvature often found in the mesial canals of molar teeth. The cones were suspended into a baseplate wax mold which was filled with a clear polyester casting resin. After the cones were removed, canals remained in the resin block, all of a similar shape, diameter and curvature. The Knoop hardness number of the resin blocks was calculated to be 22; that of dentin was between 40-72. Because chelating agents are often used in small curved canals, as were simulated in this study, it is possible that the chelated canal and those used here had similar cutting characteristics (2).

In 1979, Loma Linda University School of Dentistry introduced resin blocks with simulated canals to their students. Spenst and Kahn expounded the advantages of the use of these blocks: radiographs were unnecessary, as the student could actually see the file in the canal; the student was able to see the shape the canal takes during instrumentation; the benefit of irrigation to remove chips created by filing was observed; results of filing versus reaming action in a curved canal were demonstrated; the importance of precurving of files and proper flaring techniques became apparent and finally, evaluation of different obturation methods could be made. The authors maintained that the use of this block provided the student with a better concept of what was expected of him in the performance of clinical endodontic procedures (41).

LaTurno, Corcoran, and Ellison conducted a study at the University of Michigan School of Dentistry, Ann Arbor, MI (1984). Dental students in the preclinical endodontics course were divided into groups. The first group followed the traditional program which provided technical training by means of extracted human teeth. Another group trained by using the transparent epoxy resin blocks containing simulated root canals. Use of the epoxy resin models was found to be a valuable adjunct to the teaching of preclinical endodontics. The resin models emphasize, in particular, the biomechanical principles of canal shape and length control. The teaching value of the resin models was purported to lie in their ability to illustrate the more complicated concepts of biomechanical preparation inherent in the instrumentation of curved canals (42).

Eldeeb and Boraas (1985) evaluated the effect of five brands of files on the final preparation shape of the canal using simulated root canals in clear resin blocks. This method was selected because it offered the advantage of standardizing the original canal size and shape in order to compare it with the final preparation. The authors maintained that it would have been difficult to make valid inferences on the final canal shape without determining the original anatomy of the canal before instrumentation (43).

The validity of simulated canals in resin blocks as a model for studying the shape of the prepared root canal was examined by Lim and Weber (1985). The incidence of preparing an hour-glass shape was quantitatively and qualitatively measured in fabricated canals and in canals from extracted human teeth. When the proportions of the hour-glass shaped canals from extracted teeth and simulated root canals were compared, there was no significant difference. They concluded, therefore, that the use of simulated root canals appeared valid. In addition, the blocks allow direct examination, which is invaluable in understanding the mechanics of root canal preparation (40).

The efficacy of two different file types (K-files and Hedstroms) was assessed by Alodeh and Dummer (1989) with simulated root canals in resin blocks. In order to determine whether the degree and position of canal curvature had any influence on file performance, a range of canal types were employed. The use of fabricated canals allowed for standardization of these canal types (straight and curved) that would not of been possible with extracted teeth (44).

A method for the production of a small series of standardized plastic blocks was offered by Schulz-Bongert and Weine in 1990. The authors reiterated the value of the simulated canals as a valid experimental model and teaching aid. Additionally, the ease of three-dimensional visualization provides a significant advantage over a two-dimensional radiograph of a extracted tooth. In this technique, x-fine smooth broaches are shaped around a round instrument to simulate a curve. A drawing is suggested so the same degree of curvature may be formed with each broach. Broaches are then placed in a type of broach holder and suspended in a mold which will accept the polyester casting resin. Grinding and polishing guidelines are provided. The resultant resin blocks will contain canals which are equidistant and standardized (45).

Finally, Baumgartner, Martin, Sabala, Strittmater, Wildey, and Quigley (1992) used histomorphometric analysis to determine the amount of canal enlargement (measures the area of each prepared canal) and composite photographs to examine canal preparations in clear resin blocks. Four methods of preparation were performed by clinicians, specially selected to have demonstrated considerable ability in the specific technique. These four methods were the step-back technique, ultrasonic preparation, use of the engine-driven Canal Master and the balanced forces technique. Each investigator described his method of canal preparation and discussed the technique of canal preparation with regard to the use of acrylic blocks for investigational purposes. While the authors asserted the validity of the resin blocks as a tool for study, their limitations were also presented. The nature of the plastic may contribute to ledging and difficulty in instrumentation with the step-back technique. The use of RC prep with copious amounts of irrigation was suggested. Ultrasonic vibrations may be slowed by the acrylic when the cavi-endo is used. The acrylic may also clog the endosonic file/diamond while intracanal dentin would not. A problem with the engine-driven Canal Master occurred due to the plastic melting from the friction, therefore, no resistance was felt when a curve was encountered. In addition, generation of plastic chips caused bogging down of the instrument. Wildey speculated this may be the result of the instrument threading into instead of cutting the plastic. Gates

Glidden burs used too vigorously in the balanced force technique may deform the plastic. Also, accumulation of debris may result in more rapid transportation of the apical portion of the canal than would occur in a tooth. However, instrumenting with balanced forces, a nonaggressive cutting tip on the instrument, and a minimum preparation were easily demonstrated using the resin block (46).

MATERIALS AND METHODS

Sixty ENDO-VU blocks (#001); Pecina & Assoc. Inc., Waukegan, IL) with simulated canals were selected for this study. The blocks were divided into twenty groups of three blocks each, blocks for each individual group were selected by arranging those canals with the most similar curvatures and working lengths together. The curvature of all blocks used was approximately 30 degrees. Working lengths were determined by placing a #15 file with a silicone stop to the full length of the canal just short of the reservoir provided at the apex. The majority of working lengths were established at 18 mm, but a few blocks had working lengths set at 18.5 and 19 mm. Each group was marked with a number of dots designating groups from one to twenty. Each individual block was marked to identify the preparation procedure that would be used: one blue dot designated conventional hand instrumentation with a flared preparation, two red dots denoted hand instrumentation with the Nitinol "MAC" files and three black dots signified instrumentation with the NT-matic automated device and its corresponding files. Prior to canal preparation, photos were taken of each group of blocks.

One operator prepared all 60 canals. The following preparation procedures were followed: conventional hand preparation was accomplished with Kerr K-flex files and Kerr Hedstrom files. The initial apical file (IAF) for each canal was a #15 K-flex file. Canals were instrumented up to a #35 master apical file (MAF) employing circumferential filing and using K-flex files and Hedstrom files in an alternating fashion. (This operators prior experience in preparing simulated canals, identified that the use of Hedstrom files helped to minimize the amount of resin shavings that accumulated at the apex of the canal.) Additionally, apices were kept patent throughout the procedure with a #15 K-flex file. An unlimited amount of water was allowed for use as an irrigant, but no other chelating agents nor lubricants were used. Following the flaring procedures as described by Weine (1), the preparations were flared three sizes larger than the MAF, to a final flare (FFL) of size #50. Hedstrom files only were used for flaring and the #35 (MAF) was used to recapitulate between each successive flaring file.

The second preparation followed the same technique as described above, however the hand "MAC" Nitinol file (NT,Co.,Chattanooga, TN) was used throughout the preparation procedure. No other file system was employed for flaring. Again, unlimited amounts of water was allowed as an irrigant and the IAF, MAF, and FFL were #15, #35 and #50, respectively. The canal apex was kept patent with a #15 Nitinol file.

The final preparation procedure used the NT-matic System (NT, Co., Chattanooga, TN) , which is an automated rotary handpiece that accepts Nitinol latch-type files, the NT file, made specifically for this device (Figs. 5 and 6). Like the "MAC", this is a machined file that incorporates two different designs. However, the NT design differs according to size. In sizes 15 through 35, flats instead of blades make up the cutting spirals (Fig. 7). The manufacturer claims this results in a planing action instead of a screwing action, common to other rotary handpieces. Larger sizes (#40-60) are designed with two or more spiralled blades which are not parallel and which intersect along the shaft of the instrument (Fig. 8). The manufacturer's suggested instrumentation procedures were followed. All NT files are used in a 16:1 gear reduction contra-angle handpiece with preparation speed maintained at the suggested 340 RPM. The same progression of file sizes were followed as in the other preparations, working from a IAF of #15 to a FFL of #50. The motion advised for the NT-matic file was a nearly continuous vertical movement, advancing the file apically approximately 1/2mm per second into the canal. As soon as the working length was reached, the next larger file size was advanced. After instrumenting to a size #30, the orifice of the canal was opened with a #2

Gates Glidden drill. Although the unit is manufactured with a 1:1 contra-angle for this purpose, it was not available, so a conventional slow-speed latch-type handpiece was used. Instrumentation continued to a #35 and was followed by the #40, 45, and 50 flaring files that were suggested to be used in a circumferential filing motion. The #35 file was replaced in the handpiece and used for recapitulation between each flaring file. Unlimited amounts of water were allowed and the apex was kept patent with a #15 "MAC" hand file.

In all three instrumentation procedures, the canals were neither masked nor covered in any manner in order to evaluate the negotiation of the Nitinol files in a curved canal as compared with that of the stainless steel files. The preparation time for each canal was recorded and an average time for each method was calculated. Post-preparation photos were taken of each set of blocks at the same object-film distance as the pre-preparation photos.

Qualitative Analysis

The pre- and post-operative photos were used to produce Xeroxed enlargements, at a magnification of approximately 771%. Separate tracings were made from the enlarged photos of each unprepared canal and then each prepared canal, these tracings could then be superimposed and evaluated for differences in canal shape before and after preparation. The use of superimposed tracings is a method similar to that used by Lim and Weber in their 1985 study on extracted teeth (11).

Quantitative Analysis

The same Xeroxed enlargements were used to make a quantitative assessment of each method of canal preparation. A Digital Planimeter, (Planix 7, The Lietz Company, Overland Park, KS) a device commonly used in drafting and surveying to measure area, was employed to measure relative increases in canal size following preparation (Figs. 9 and 10). Using the enlarged representations of each group of blocks, the planimeter was used to trace the periphery of each canal. After completing three tracings, an average area in square centimeters was calculated. In order to properly evaluate the amount of preparation at significant areas of the canal, the canals were divided into equal apical, middle, and coronal portions. Therefore, the amount of apical preparation, overall preparation, and coronal flaring produced by each method could be assessed relative to the unprepared canal and to each other.

Figure 5: NT-matic gear reduction handpiece

Figure 6: #15-40 NT files

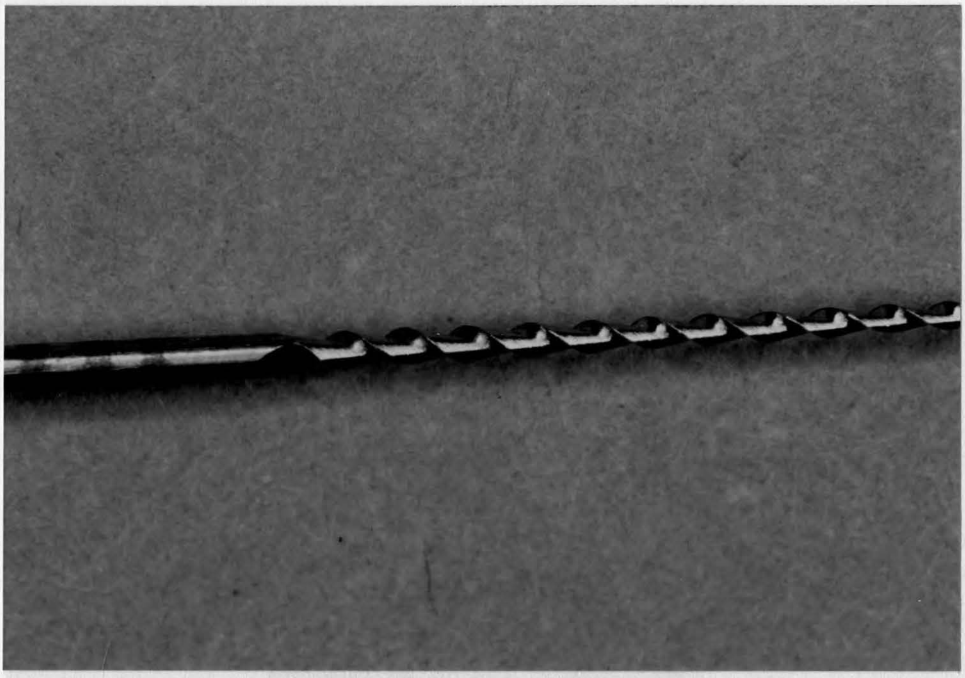


Figure 7: #25 NT file

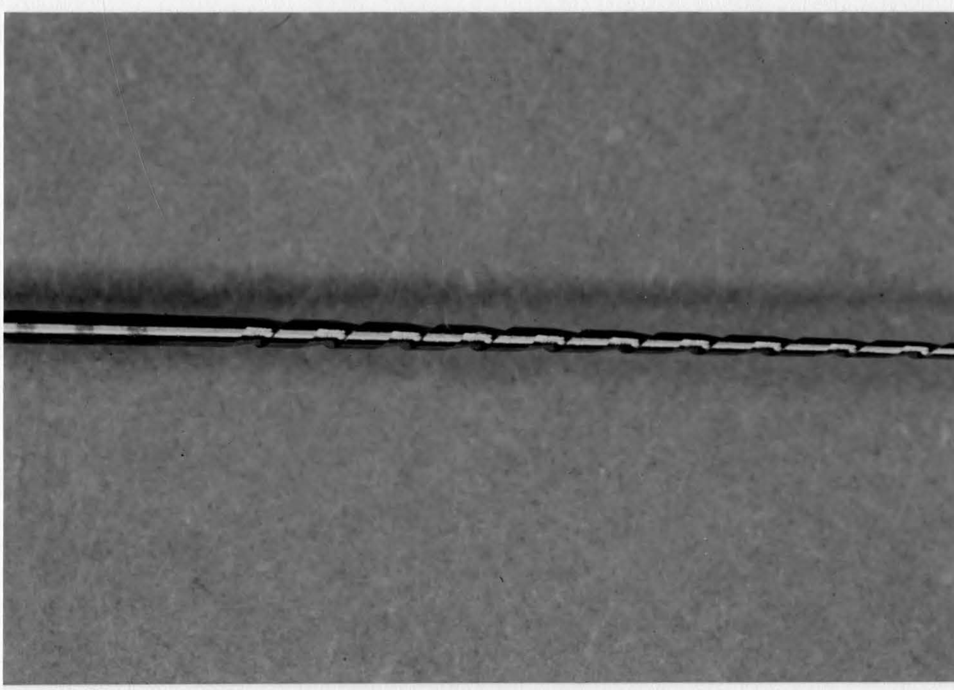
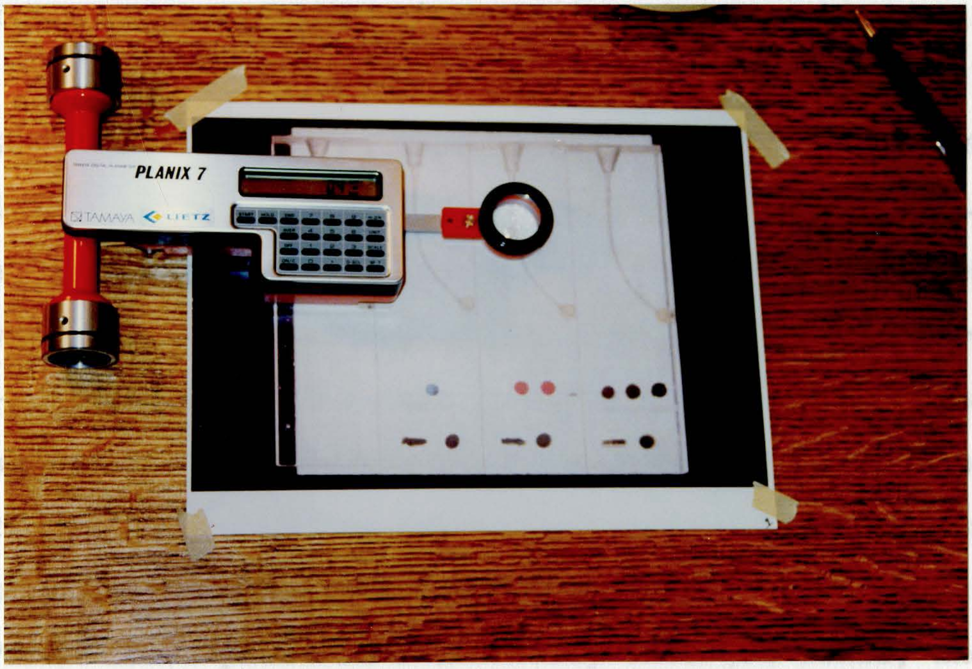


Figure 8: #40 NT file



Figures 9 and 10: Digital Planimeter

RESULTS

One group of blocks (group 4) was discarded due to procedural errors, which occurred in preparation, not attributed to the method of instrumentation. All resulting observations and calculations were made based on 19 groups of blocks or 57 preparations.

Mean instrumentation times were 13.20, 11.30, and 10.11 minutes for conventional hand instrumentation, instrumentation with the "MAC" file, and instrumentation with the NT-matic, respectively. Therefore, the slowest preparation times resulted with conventional hand instrumentation and the quickest with the NT-matic.

Qualitative Analysis

Generally, all three techniques were able to enlarge the canals while maintaining the original canal shape. The degree to which the canals were enlarged with each method, however, was quite different. Evaluation of the pre- and post-preparation photographs and the superimposed tracings (Figs. 11 through 28) revealed the following: manual instrumentation with the K-flex and Hedstrom files resulted in the most overall canal enlargement; instrumentation with the "MAC" files produced a minimally enlarged canal; and the NT-matic resulted in a moderately prepared canal.

Specifically, conventional hand instrumentation produced a continuously tapered preparation from the apex to approximately the coronal 1/3, at which point a well-flared orifice became evident. The preparation, resulting from use of the "MAC" file, appeared as a preparation only slightly larger than the original canal from the apex to the coronal 1/4 where a slight flare was exhibited. Preparation with the NT-matic handpiece produced a continuously tapered preparation from apex to orifice with a discrete transition from the body of the preparation to the flare. Some of the NT-matic preparations exhibited slight constrictions or elbows in the canal at points just apical to the coronal one-third and then again in the middle of the apical one-third.

Because the canals were not covered, the action of the files in the canals could be observed during preparation. It appeared that the two Nitinol file systems, regardless of technique, were able to follow and negotiate the curvature of the canals more closely than the stainless steel files. If strict adherence to the principles of curved canal preparation with stainless steel files were not followed, the phenomenon, first described by Weine et al (2), of "zipping" could be observed. Nonetheless, with the exception of the "MAC" files, some degree of elliptication or "zipping" of the apex by the action of the file in the canal was almost always perceptible during instrumentation.

There was a noticeable difference in the ease with which the canals were instrumented. The alternate use of the K-flex files and the Hedstrom files made advancement from smaller to the next larger size files quite easy. Flaring of the preparation was efficiently preformed as the flaring files could be placed to their desired length with little effort. However, preparation was significantly more tedious with "MAC" file. Positioning of each file to the full working length was easily accomplished up to a size #25, but from that point on increased effort was required to instrument up to the MAF. In addition, flaring proved to be extremely difficult, the first flaring file was never able to achieve its desired working length (1 mm short of the working length) on its initial placement into the canal, recapitulation with smaller size files was continually necessary before instrumentation with the flaring files was effective. The files always felt tight within the canals even at the completion of flaring. Conversely, instrumentation with the NT-matic was quite effortless and little resistance was felt with any of the files.

Differences in the amount of debris generated by each method was observed. A large amount of acrylic shavings was generated by the stainless steel files. Copious amounts of irrigation and repeated violation of the apex with the size #15 file, to maintain patency, was necessary to avoid blocking the canal with the shavings. The use of the

Hedstrom file tended to aid in transporting the debris coronally, reducing its accumulation in the apical portion of the canals. The accumulation of acrylic shavings was not as much of a concern with the Nitinol files, while irrigation and maintaining apical patency were both necessary, these procedures were needed less often.

Quantitative Analysis

One acrylic block, in group 1, was used as a control in order to judge the accuracy of pre- and post-preparation photos. The overall area of the control block in the pre- and post-preparation photo, was 2.663 and 2.667 square centimeters respectively, representing an error of .1 percent.

The areas in square centimeters of the coronal, middle, and apical portions of each canal, prior to and following preparation, are listed in Table 1. The difference or increase in area from pre-preparation to post-preparation for the same portions of each canal was calculated and is shown in Table 2. Tables 3 and 4, respectively, represent the average area of canal size before and after preparation and the average increase in area as a result of preparation.

These values express similar findings quantitatively to what was displayed by the qualitative analysis. While the mean area of each portion of the canals was quite similar prior to instrumentation, a significant difference in area was found between all three methods following preparation

(Table 5). Conventional hand instrumentation resulted in greater preparation overall with the most pronounced taper from apical to coronal area. Instrumentation with the "MAC" file created a minimally enlarged preparation with only a slight increase in area from apex to crown. Analysis of the mean area of canal enlargement with the NT-matic revealed an increase in canal size from apical to middle portions followed by a slight decrease in area at the coronal portions. In other words, the middle portion of the NT instrumented canals actually had the greatest overall increase following preparation.

The Student Newman-Keuls Test (Table 6) was used to determine the specific differences between groups. At the coronal level, significant differences were found between all three instrumentation techniques ($p<0.05$), at $p<0.01$, however, no significant differences were found between conventional hand instrumentation and the NT-matic or between the NT-matic and the "MAC'. Significant differences at $p<0.01$ were found in the middle portion of the canals with all three methods. At the apical level significant differences were found ($p<0.01$) between conventional hand and "MAC" instrumentation but not for conventional hand versus NT-matic. A significant difference was found at $p<0.05$ between the NT-matic and "MAC" methods, but not at $p<0.01$.

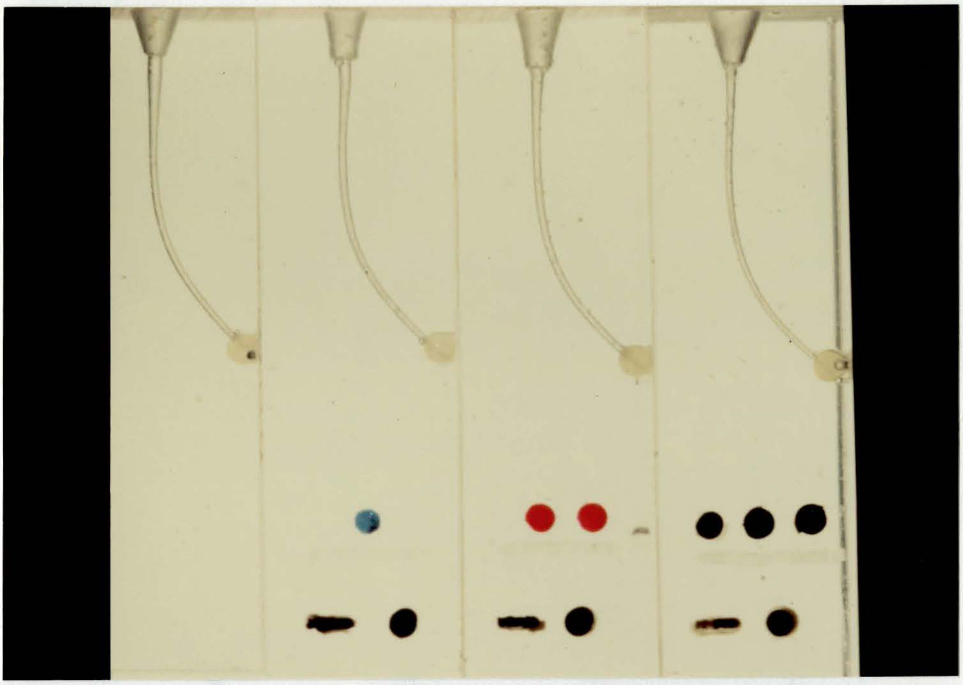


Figure 11: Group 1 - Pre-preparation including control

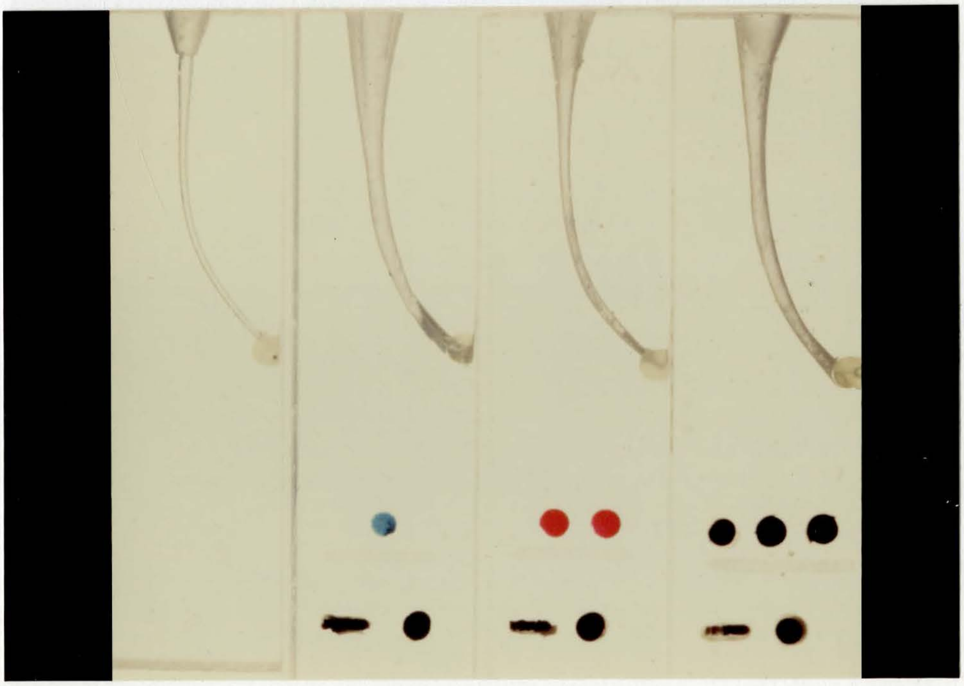


Figure 12: Group 1 - Post-preparation including control

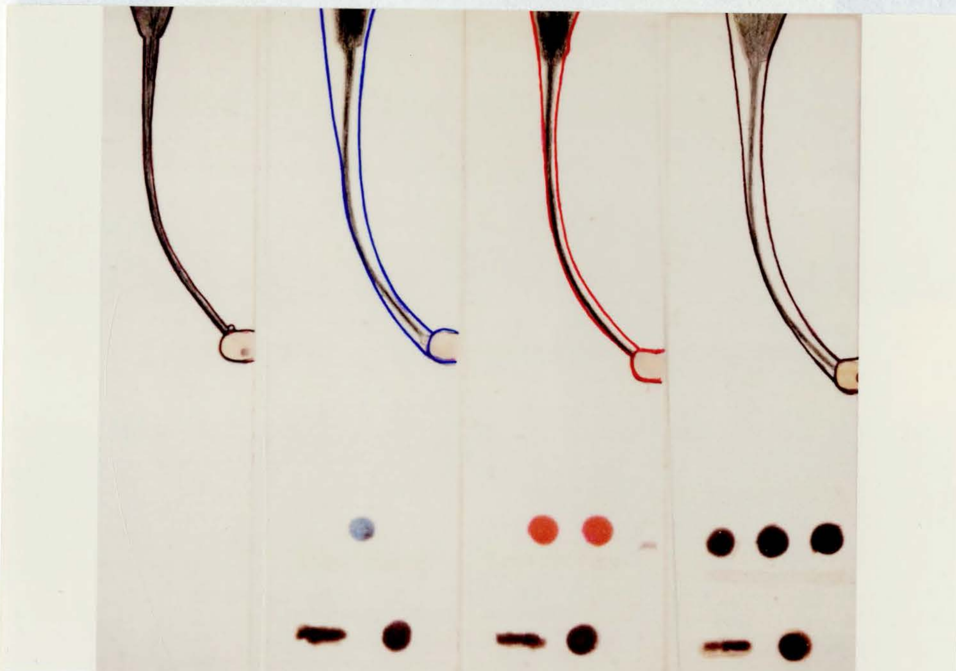


Figure 13: Group 1 - Super-imposed tracing

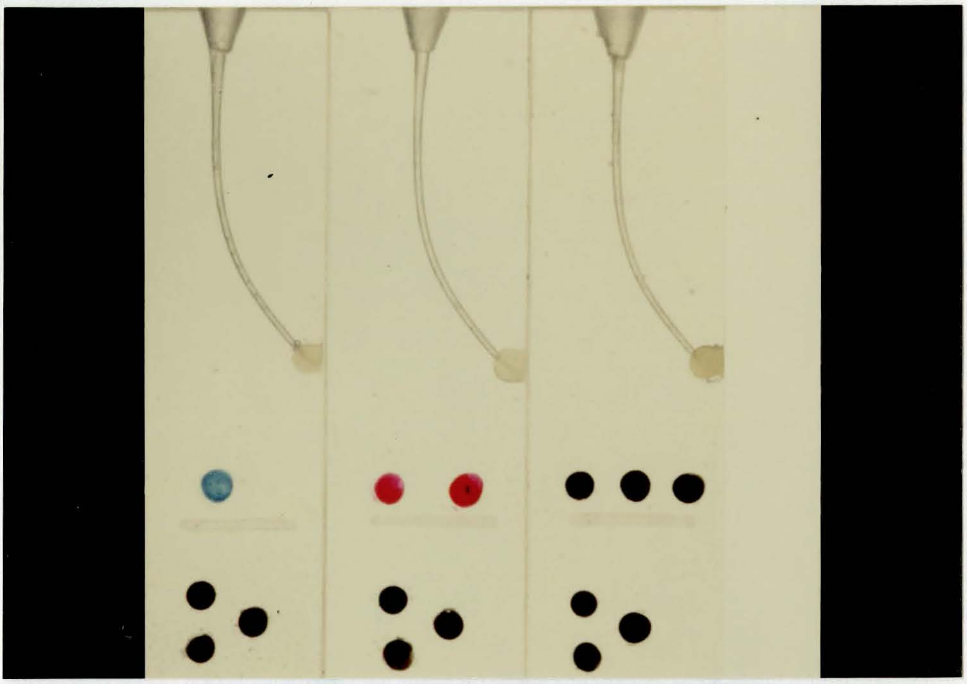


Figure 14: Group 7 - Pre-preparation

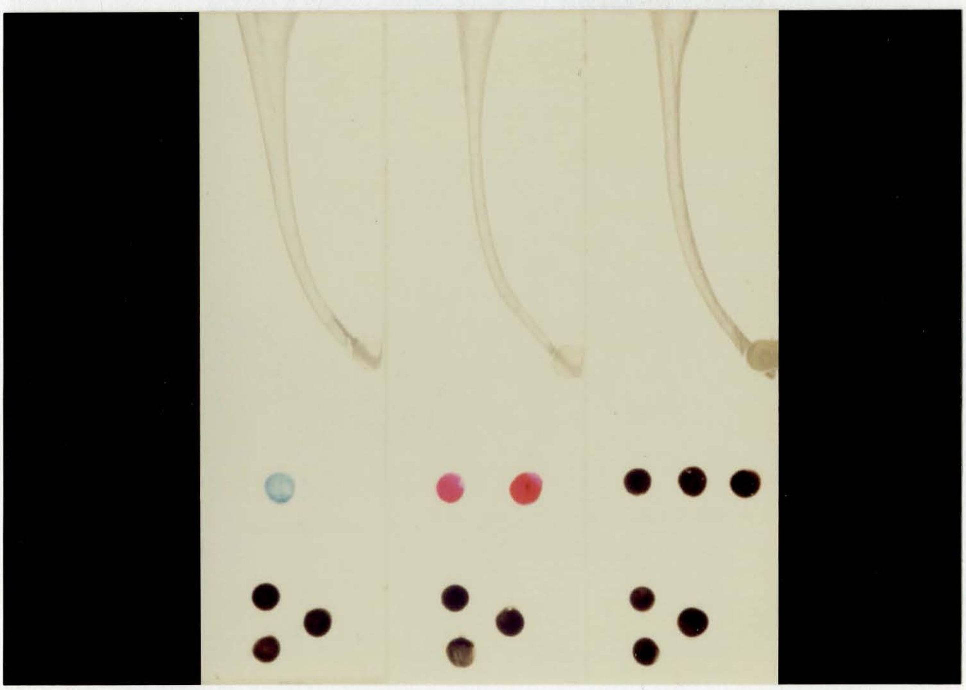


Figure 15: Group 7 - Post-preparation

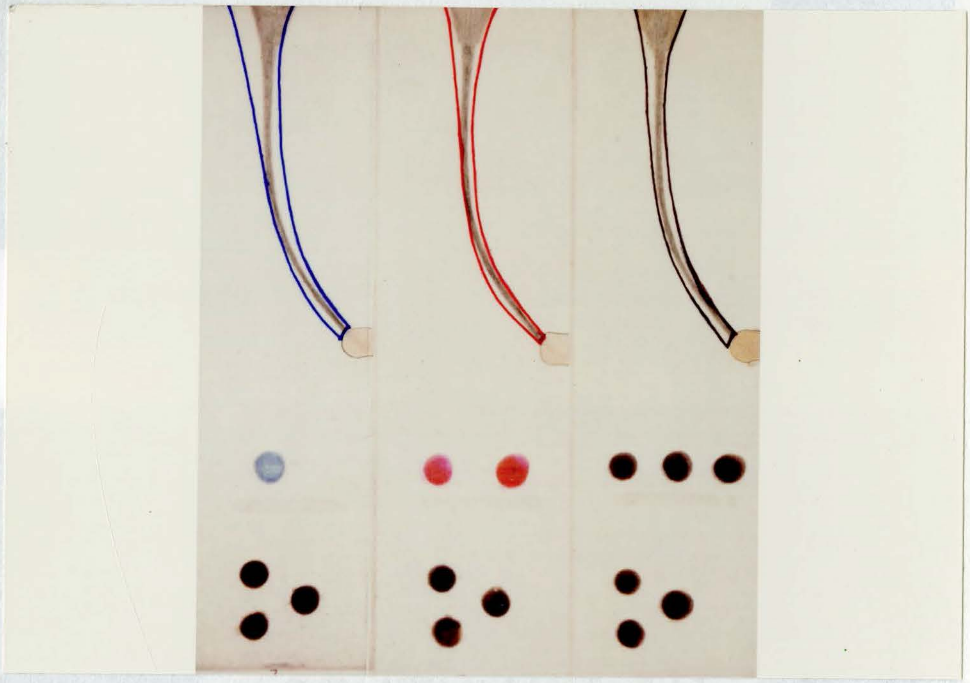


Figure 16: Group 7 - Super-imposed tracing

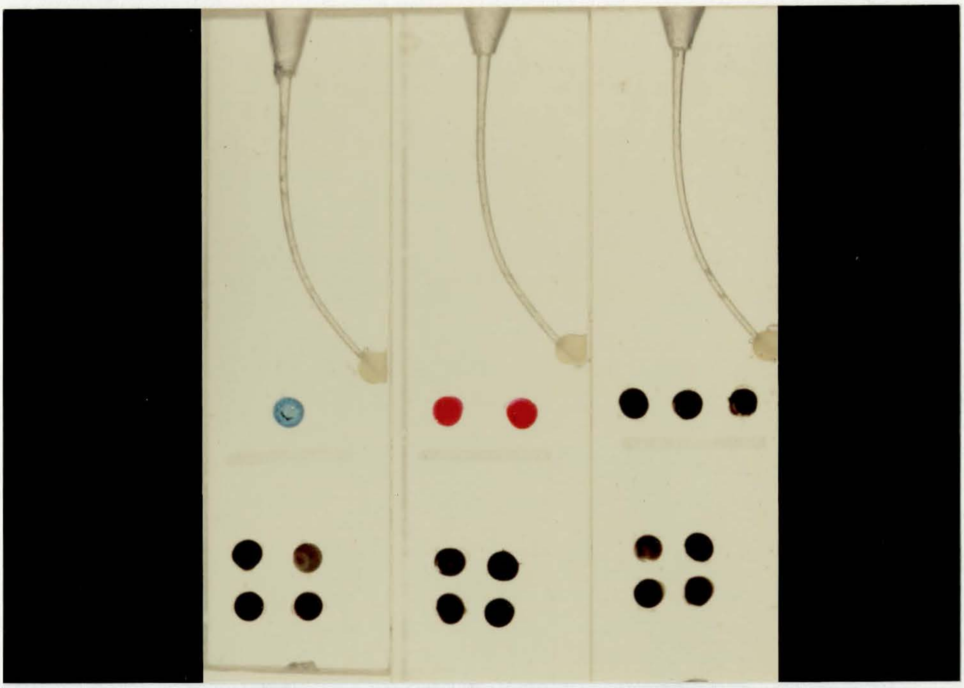


Figure 17: Group 8 - Pre-preparation

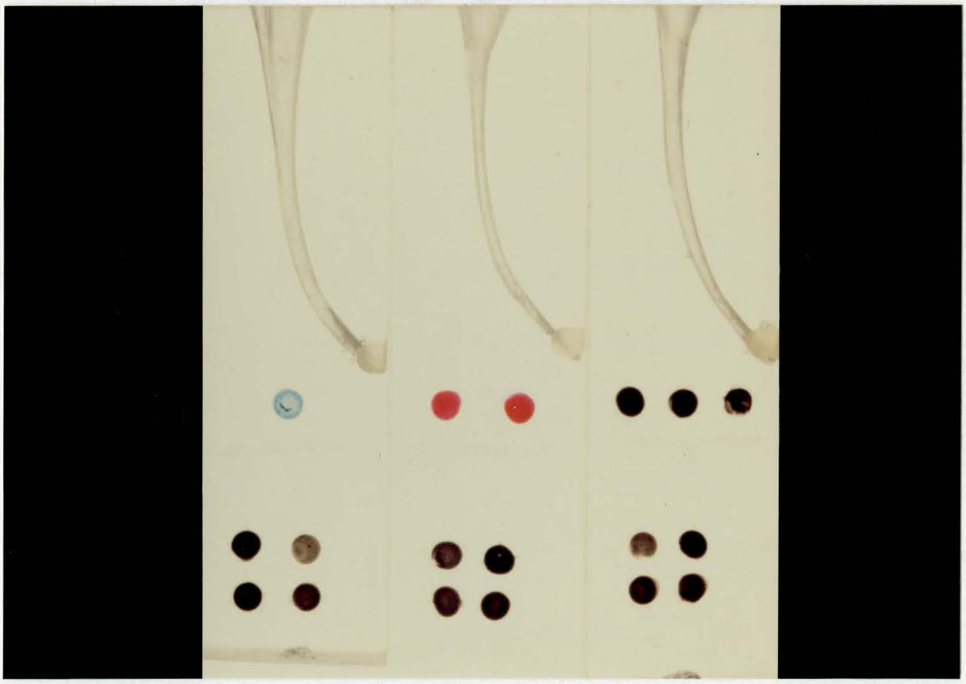


Figure 18: Group 8 - Post-preparation

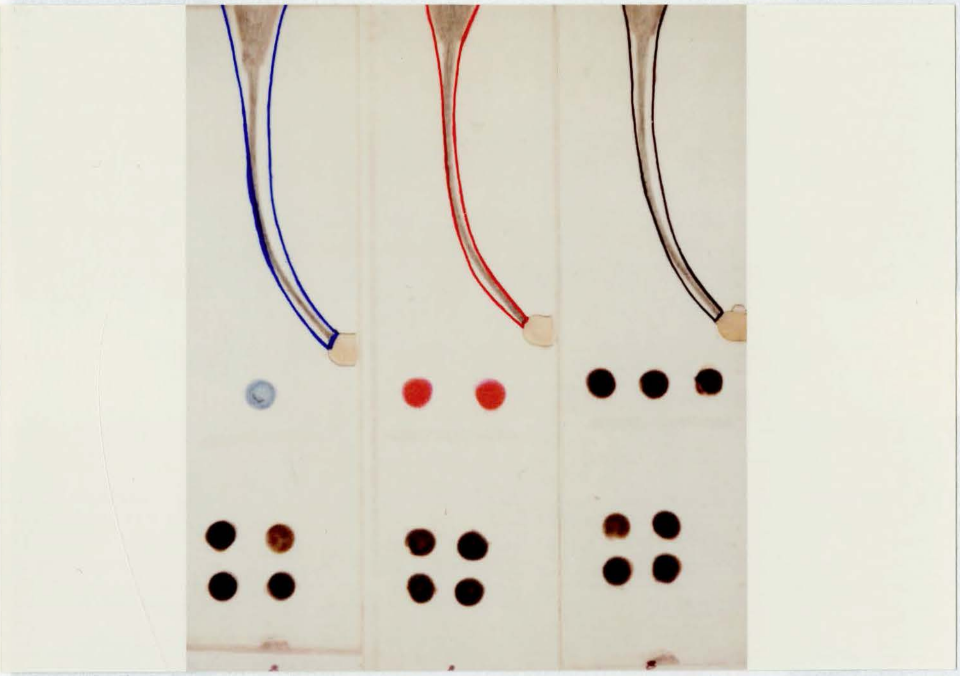


Figure 19: Group 8 - Super-imposed tracing

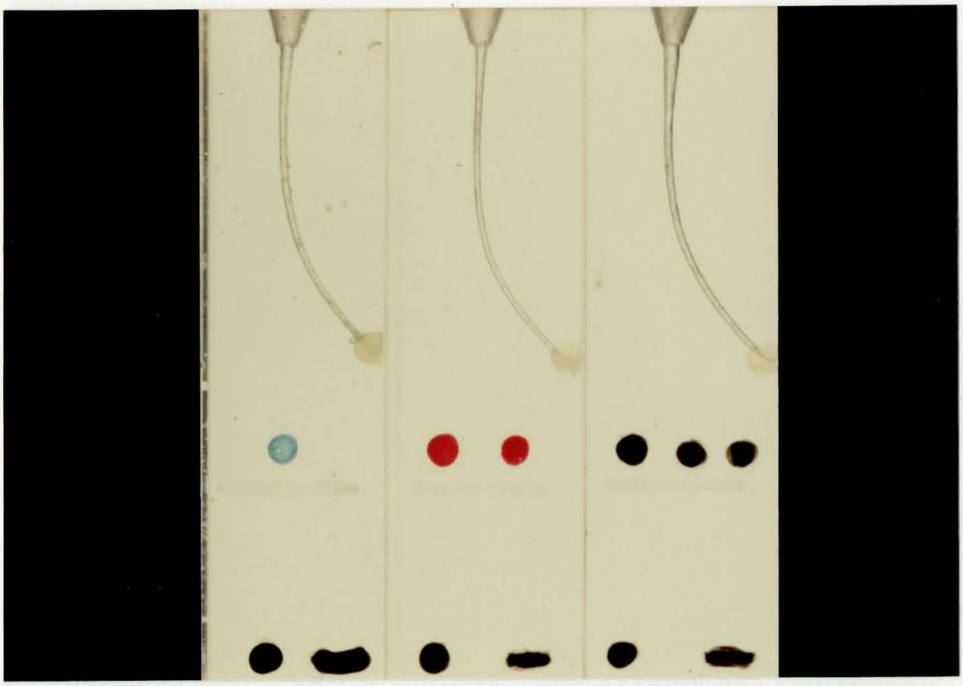


Figure 20: Group 9 - Pre-preparation

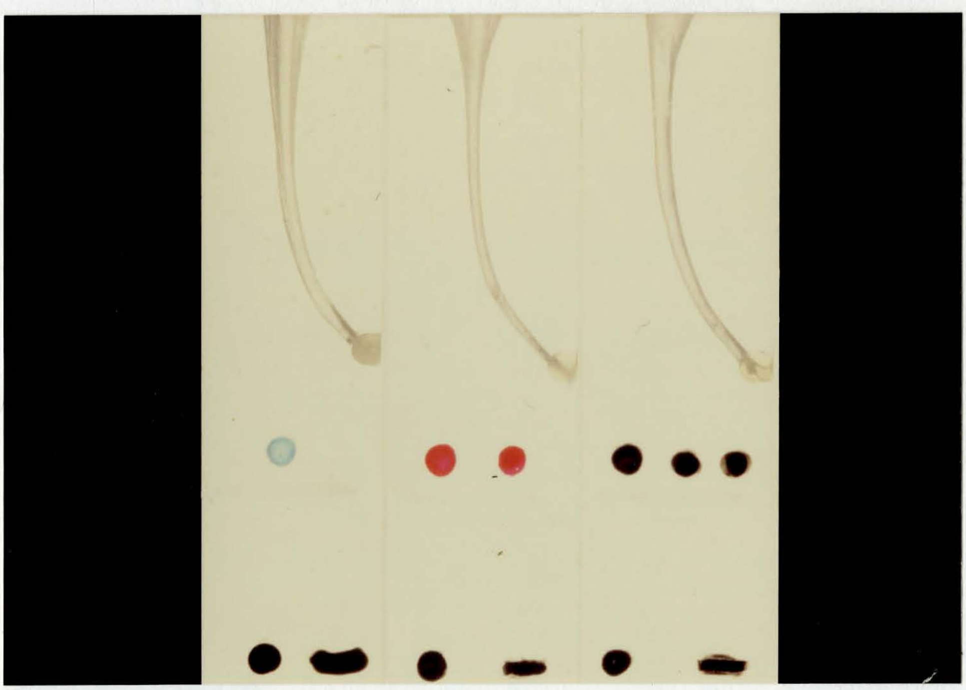


Figure 21: Group 9 - Post-preparation

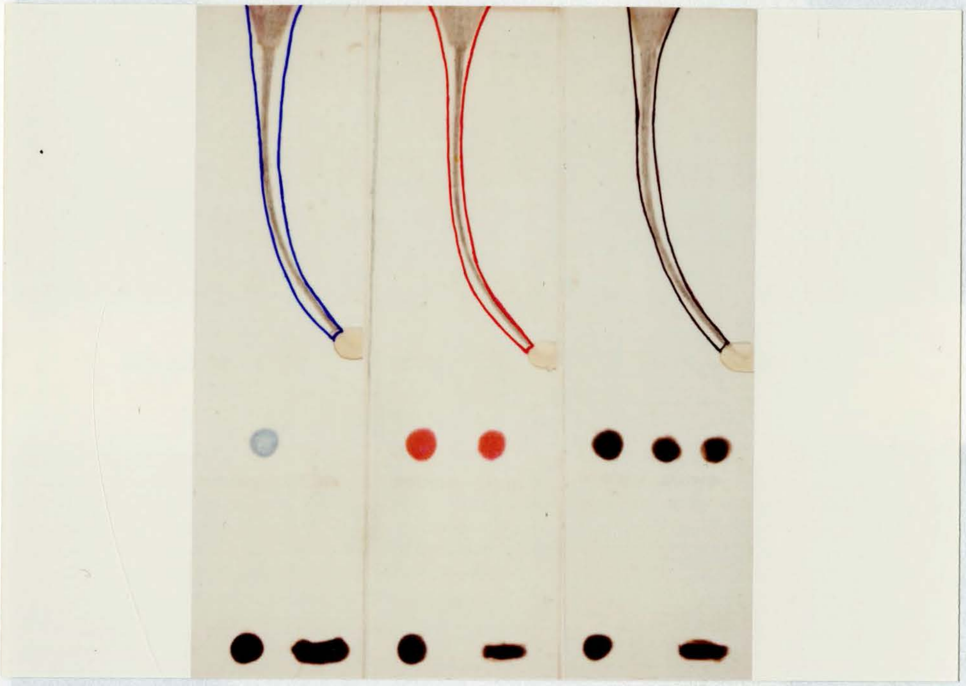


Figure 22: Group 9 - Super-imposed tracing

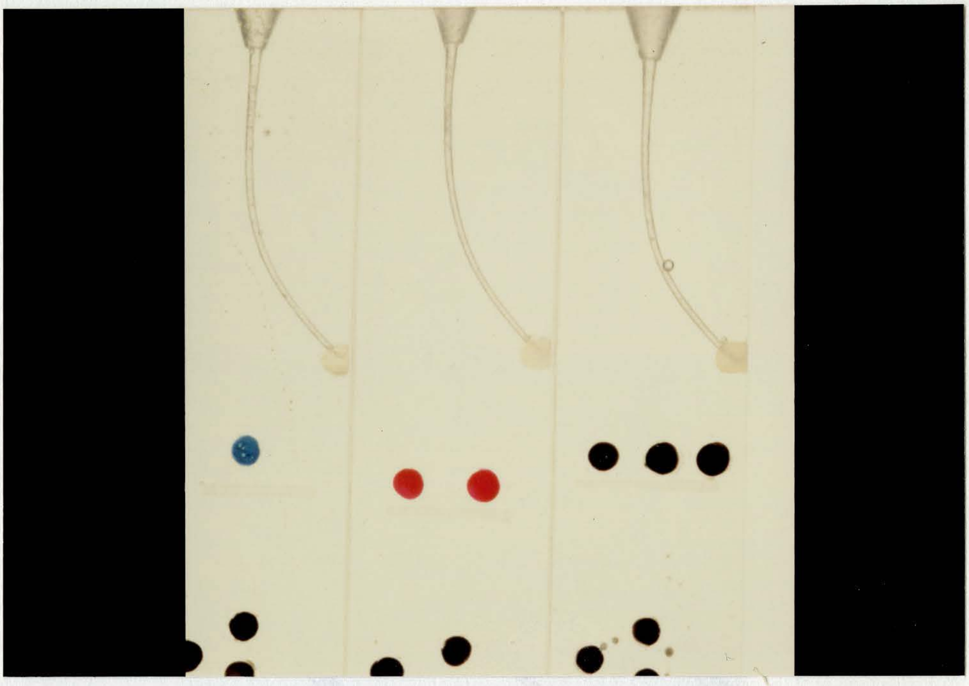


Figure 23: Group 15 - Pre-preparation

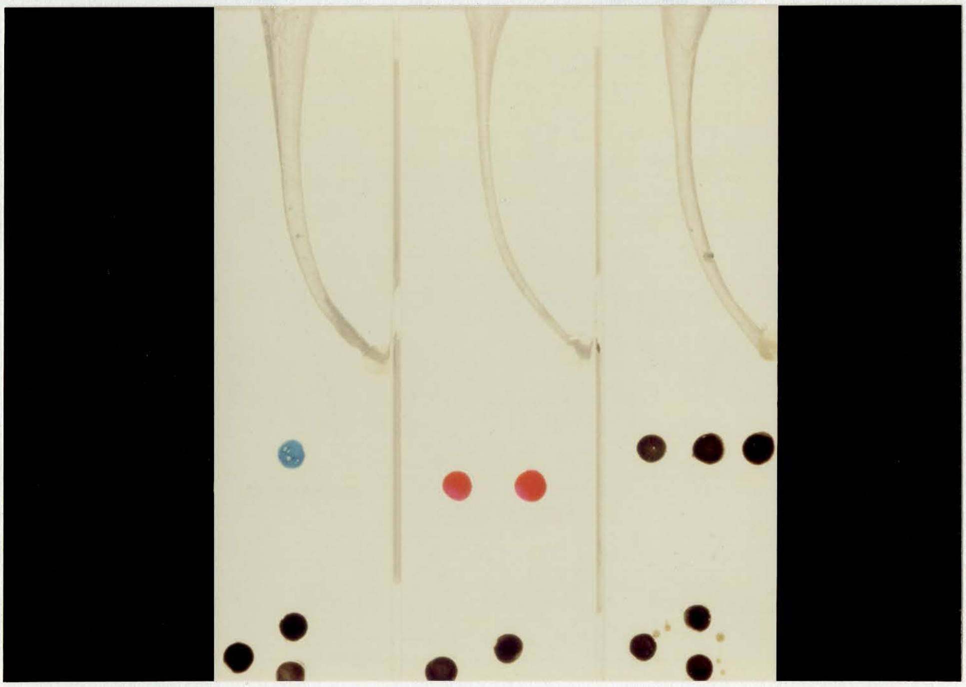


Figure 24: Group 15 - Post-preparation

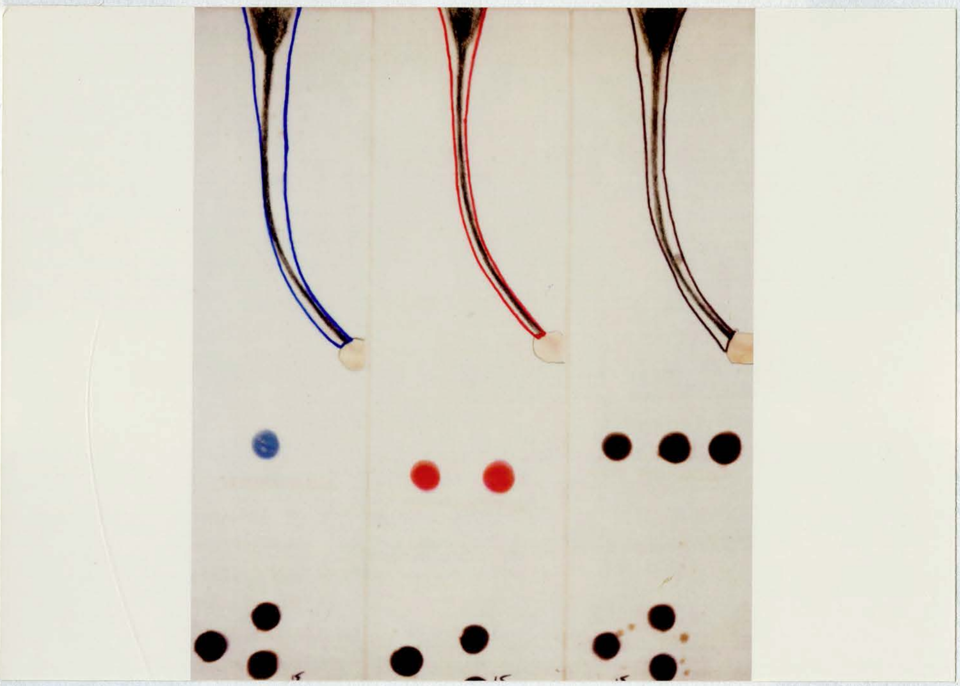


Figure 25: Group 15 - Super-imposed tracing

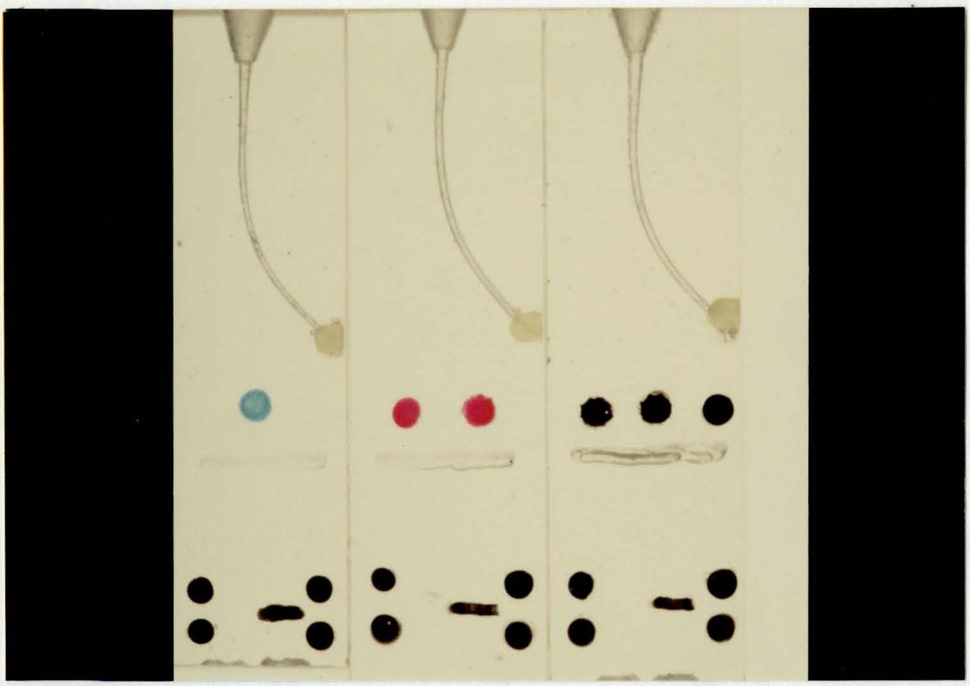


Figure 26: Group 20 - Pre-preparation

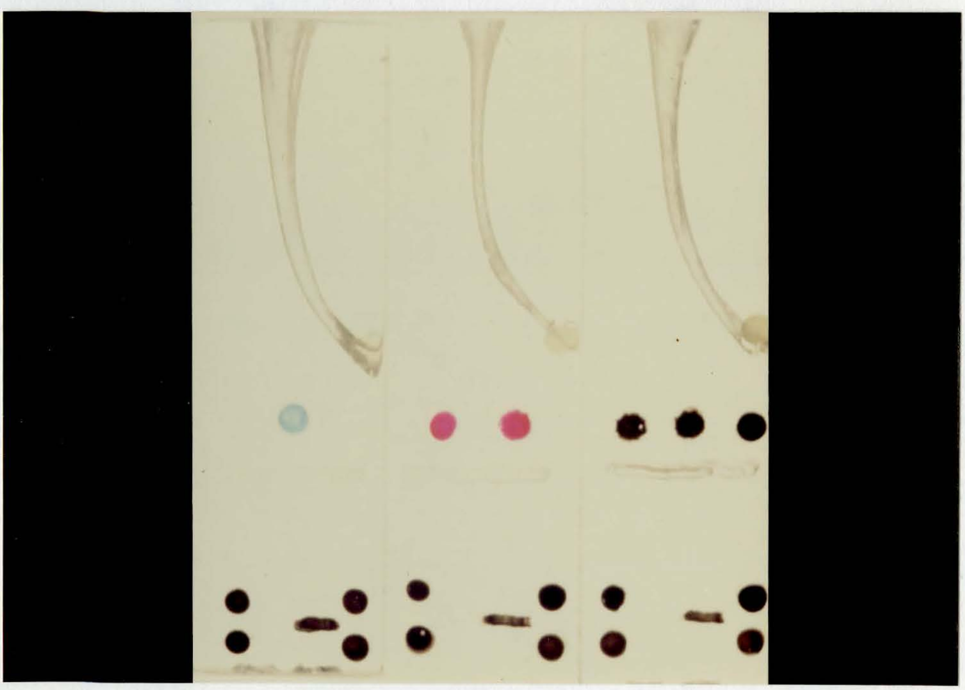


Figure 27: Group 20 - Post-preparation

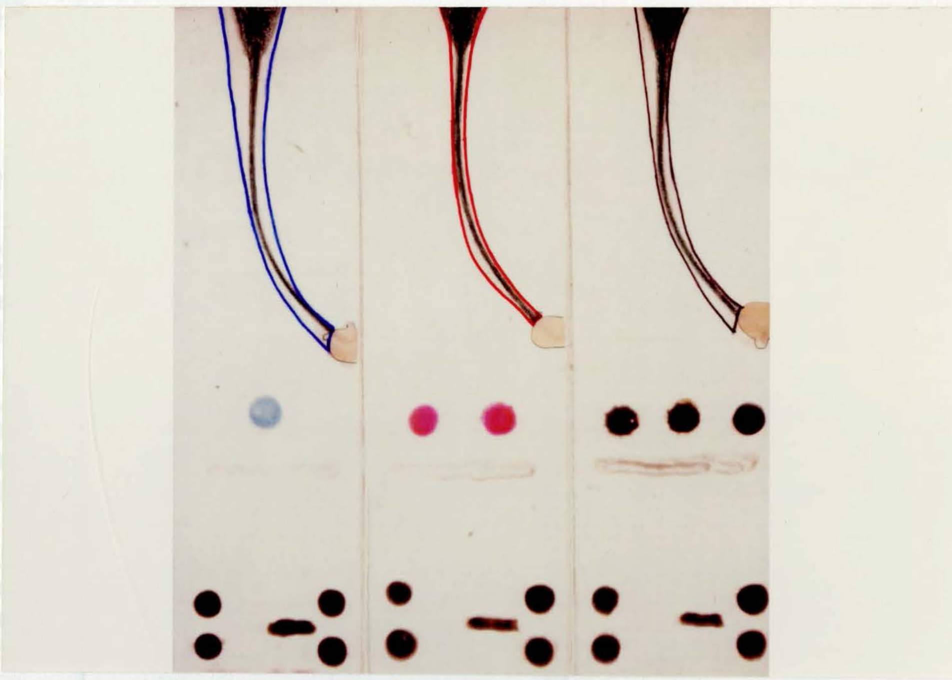


Figure 28: Group 20 - Super-imposed tracing

TABLE 1

Area of Canals (sq cm) - Pre-Preparation and Post-Preparation

	Pre-prep Photo	Post-prep Photo
Control		
Coronal	1.63	1.60
Middle	.600	.566
Apical	.433	.500

	Pre-prep			Post-prep		
	Conv Hand	"MAC"	NT-matic	Conv Hand	"MAC"	NT-matic
Group 1						
Coronal	1.50	1.90	1.60	3.03	2.10	2.60
Middle	.625	.566	.566	1.47	.866	1.20
Apical	.566	.500	.580	1.23	.833	1.30
Group 2						
Coronal	1.60	1.40	1.46	3.03	1.70	2.16
Middle	.660	.700	.466	1.47	.733	1.33
Apical	.500	.466	.500	1.07	.650	1.00
Group 3						
Coronal	1.73	1.66	1.73	3.70	2.03	1.87
Middle	.566	.533	.566	1.66	.666	1.37
Apical	.666	.466	.475	1.20	.766	.900
Group 5						
Coronal	1.20	1.23	1.30	3.23	1.97	1.60
Middle	.633	.533	.600	1.36	.933	1.07
Apical	.500	.466	.466	.900	.733	.733
Group 6						
Coronal	1.73	1.93	1.83	3.33	2.23	2.47
Middle	.600	.600	.500	1.10	.866	1.20
Apical	.533	.600	.500	.666	.666	.966
Group 7						
Coronal	1.57	1.50	1.66	3.00	2.17	2.23
Middle	.566	.566	.600	1.55	.766	1.10
Apical	.475	.500	.466	1.10	.666	1.00

TABLE 1--Continued

	Pre-prep			Post-prep		
	Conv Hand	"MAC"	NT-Matic	Conv Hand	"MAC"	NT-Matic
Group 8						
Coronal	1.73	1.80	1.37	3.13	1.97	2.05
Middle	.500	.633	.533	1.37	.900	1.20
Apical	.466	.533	.466	1.13	.766	.866
Group 9						
Coronal	1.50	1.60	1.78	2.66	2.07	2.20
Middle	.450	.466	.500	1.67	.866	1.20
Apical	.433	.466	.566	1.03	.800	.966
Group 10						
Coronal	1.40	1.40	1.43	3.30	2.26	2.00
Middle	.500	.633	.666	1.60	.800	1.66
Apical	.466	.466	.433	1.20	.800	.900
Group 11						
Coronal	1.43	1.90	1.60	3.03	2.43	2.06
Middle	.466	.633	.533	1.43	1.30	1.15
Apical	.400	.600	.500	1.03	.666	.966
Group 12						
Coronal	1.50	1.10	1.47	3.13	1.80	2.13
Middle	.533	.533	.550	1.47	1.10	1.40
Apical	.433	.466	.400	1.30	.766	1.10
Group 13						
Coronal	1.90	1.90	1.80	3.10	2.23	2.40
Middle	.466	.500	.633	1.53	.833	1.30
Apical	.400	.400	.433	1.10	.733	.933
Group 14						
Coronal	1.27	1.57	1.13	3.07	1.90	2.03
Middle	.533	.533	.500	1.30	.866	1.33
Apical	.466	.466	.366	1.00	.600	.966
Group 15						
Coronal	1.40	1.33	1.87	2.87	1.70	2.23
Middle	.533	.500	.500	1.57	.833	1.20
Apical	.366	.433	.466	1.17	.666	1.10

TABLE 1--Continued

	Pre-prep			Post-prep		
	Conv Hand	"MAC"	NT-Matic	Conv Hand	"MAC"	NT-Matic
<u>Group 16</u>						
Coronal	1.66	1.50	1.50	2.93	2.07	2.10
Middle	.566	.533	.566	1.70	.866	1.33
Apical	.533	.350	.466	1.66	.766	.900
<u>Group 17</u>						
Coronal	1.60	1.36	1.57	3.23	1.97	2.03
Middle	.766	.866	.966	2.00	.933	1.27
Apical	.500	.666	.766	1.03	.766	1.33
<u>Group 18</u>						
Coronal	1.17	1.33	1.03	2.70	1.80	2.07
Middle	.600	.600	.633	1.50	.900	1.23
Apical	.400	.433	.466	.950	.833	1.03
<u>Group 19</u>						
Coronal	1.43	1.40	1.13	2.83	1.77	1.90
Middle	.700	.566	.633	1.57	.900	1.13
Apical	.550	.433	.500	1.33	.733	.966
<u>Group 20</u>						
Coronal	1.50	1.40	1.47	3.17	1.60	2.33
Middle	.533	.533	.500	1.63	.933	1.66
Apical	.433	.400	.366	1.03	.633	.966

TABLE 2

Increase in Area (sq cm) of Canals - Pre-Preparation to Post-Preparation

	Conv Hand	"MAC"	NT-Matic
Group 1			
Coronal	1.53	.200	1.00
Middle	.845	.300	.634
Apical	.664	.333	.720
Group 2			
Coronal	1.43	.300	.700
Middle	.810	.030	.864
Apical	.507	1.84	.500
Group 3			
Coronal	1.97	.370	.140
Middle	1.09	.133	.804
Apical	.534	.300	.425
Group 5			
Coronal	2.03	.740	.300
Middle	.727	.400	.470
Apical	.400	.267	.267
Group 6			
Coronal	1.60	.300	.640
Middle	.500	.266	.700
Apical	.133	.066	.466
Group 7			
Coronal	1.43	.670	.570
Middle	.984	.200	.500
Apical	.625	.166	.534
Group 8			
Coronal	1.40	.170	.680
Middle	.870	.267	.667
Apical	.664	.233	.400
Group 9			
Coronal	1.16	.470	.420
Middle	1.22	.400	.700
Apical	.597	.334	.467

TABLE 2--Continued

	Conv Hand	"MAC"	NT-matic
Group 10			
Coronal	1.90	.860	.570
Middle	1.10	.167	.994
Apical	.734	.334	.467
Group 11			
Coronal	1.60	.530	.460
Middle	.964	.667	.617
Apical	.630	.066	.466
Group 12			
Coronal	1.63	.700	.660
Middle	.937	.567	.850
Apical	.867	.300	.700
Group 13			
Coronal	1.20	.330	.600
Middle	1.06	.333	.667
Apical	.700	.333	.500
Group 14			
Coronal	1.80	.330	.900
Middle	.767	.333	.830
Apical	.534	.134	.600
Group 15			
Coronal	1.47	.370	.360
Middle	1.04	.333	.700
Apical	.804	.233	.634
Group 16			
Coronal	1.27	.570	.700
Middle	1.13	.333	.764
Apical	1.13	.416	.434
Group 17			
Coronal	1.63	.610	.460
Middle	1.23	.067	.304
Apical	.503	.100	.564
Group 18			
Coronal	1.53	.470	1.04
Middle	.900	.300	.597
Apical	.550	.400	.564

TABLE 2--Continued

	Conv Hand	"MAC"	NT-matic
Group 19			
Coronal	1.40	.370	.770
Middle	.870	.433	.497
Apical	.780	.300	.466
Group 20			
Coronal	1.67	.200	.860
Middle	1.10	.400	1.16
Apical	.597	.233	.600

TABLE 3

Mean Area (sq cm) of Canals - Pre-Preparation and Post-Preparation

	Mean Area (sq cm) Pre-prep			Mean Area (sq cm) Post-prep		
	Conv Hand	"MAC"	NT-matic	Conv Hand	"MAC"	NT-matic
Coronal	1.52	1.54	1.51	3.08	1.99	2.13
Middle	.568	.580	.580	1.52	.887	1.28
Apical	.478	.479	.483	1.11	.729	.994

TABLE 4

Mean Increase in Area (sq cm) of Canals - Pre-Preparation to Post-Preparation

	Conv Hand	SD	"MAC"	SD	NT-matic	SD
Coronal	1.561	.2422	.451	.1981	.623	.2351
Middle	.955	.1828	.312	.1564	.701	.1964
Apical	.629	.2021	.336	.3789	.514	.1084

(SD=Standard deviation)

TABLE 5

F-Test (One Way Analysis of Variance)

	Mean Inc. (sq cm)	SD	SEM
Coronal*			
Conv Hand	1.561	0.2422	0.0556
"MAC"	0.451	0.1981	0.0455
NT-matic	0.623	0.2351	0.0539
Middle**			
Conv Hand	0.955	0.1828	0.0419
"MAC"	0.312	0.1564	0.0359
NT-matic	0.701	0.1964	0.0451
Apical***			
Conv Hand	0.629	0.2021	0.0464
"MAC"	0.336	0.3789	0.0869
NT-matic	0.514	0.1084	0.0249

(SEM= Standard error of the mean)

* Differences in canal enlargement at coronal level are significant @ $p<0.001$, $F=1.328$.

** Differences in canal enlargement at middle level are significant @ $p<0.001$, $F=61.978$.

*** Differences in canal enlargement at apical level are significant @ $p<0.003$, $F=6.329$.

TABLE 6

Student Newman-Keuls Test (Multiple Comparisons)

Coronal	
Conv Hand vs "MAC"	Significant @ $p<0.05$, $q=21.412$ Significant @ $p<0.01$
Conv Hand vs NT-matic	Significant @ $p<0.05$, $q=18.092$ Not significant @ $p<0.01$
NT-matic vs "MAC"	Significant @ $p<0.05$, $q=3.320$ Not significant @ $p<0.01$
Middle	
Conv Hand vs "MAC"	Significant @ $p<0.05$, $q=15.631$ Significant @ $p<0.01$
Conv Hand vs NT-matic	Significant @ $p<0.05$, $q=6.174$ Significant @ $p<0.01$
NT-matic vs "MAC"	Significant @ $p<0.05$, $q=9.457$ Significant @ $p<0.01$
Apical	
Conv Hand vs "MAC"	Significant @ $p<0.05$, $q=4.993$ Significant @ $p<0.01$
Conv Hand vs NT-matic	Not significant @ $p<0.05$, $q=1.955$ Not significant @ $p<0.01$
NT-matic vs "MAC"	Significant @ $p<0.05$, $q=3.038$ Not significant @$p<0.01$

DISCUSSION

The overall impression gathered from this study indicates that the Nitinol file systems may have an application in endodontic therapy, however not as the sole instrument used in preparation. It must be understood that this is only an initial study which gives a preliminary indication of the possiblities for the use of the Nitinol file.

The results of this study must be evaluated after consideration of the following factors; first, the simulated canals used in these preparations (#001;Pecina & Assoc.,Waukegan, Il) were moderately easy canals to prepare. The canals would accept an initial apical K-flex file of size #15 and while a #15 Nitinol file was also used as the initial apical file it advanced easily into the canal and effective instrumentation did not really begin until the #20 file was employed. Secondly, the curvature of these canals (30 degrees), while representing a large portion of canals which might be found in clinical situations, does not fairly simulate more extreme curvatures that are often encountered under in-vivo conditions. Finally, the canals were not covered at any time during preparation. A significant advantage of using the clear acrylic blocks, as mentioned previously by several authors (2, 40, 41, 42), is the ability to visualize intracanal procedures as they are preformed. While this is a valuable benefit from an instructional point of view, it again, does not simulate true clinical conditions.

Instrumentation times for both Nitinol file systems were shorter than for conventional hand instrumentation. This finding may be attributed to several factors. The use of two sets of files of the same size, as in alternating the K-flex files with the Hedstrom files, is inevitably going to take more time than if one file system is used. Instrumentation with the "MAC" files was more difficult at larger sizes, however, instrumenting up to the larger sizes was faster. This was due to the previously mentioned fact, that a #20 "MAC" file could of been used as the IAF, no significant preparation occurred until larger size files were used. Similarly, the #15 NT-matic file, did not provide significant cutting ability and instrumenting with larger NT-matic was generally effortless. In addition, the MAF used in this study was a #35, McSpadden suggests instrumentation with the NT-matic should proceed to a size #45. Instrumentation up to a #45 file would not generally be appropriate in canals with a 30 degree curvature when using conventional file systems. Therefore, the time required for preparation, with the NT-matic would of increased had two further file sizes been used.

The fact that the simulated canals initially accepted Nitinol file sizes that were larger than the #15 K-flex file suggests that a discrepancy exists between files of the same numbered sizes in the two systems. Perhaps, the particular flute design of the "MAC" and the NT-matic files yields a smaller file. This may also explain the recommendation to prepare canals up to a size #45.

A significant difference was found in canal size in the coronal and middle portions between all three methods. Conventional hand instrumentation consistently produced larger preparations in those areas of the canals. This becomes an important observation when the other phases in root canal therapy, debridement and obturation, are considered.

Weine (1) defines a flared preparation as one which is proportionally enlarged away from the most apical portion of the canal. He further states that the use of flaring greatly enhances canal cleansing and ability to seal the apex. Some of the physical advantages of the flared preparation are described: because the canal is much wider, the intracanal irrigants have more room to gain access to the irritants and necrotic debris; the wider coronal portion allows for easier placement of finger spreaders and gutta percha cones; and the desired shape of a canal preparation is obtained - as narrow as possible at the apex consistent with cleaning the canal and as wide as possible at the orifice consistent with not gutting the crown.

While for all three methods, the motions of creating a flared preparation (step-back with increasingly larger file sizes) were performed, this desired shape was not necessarily the result in the "MAC" and NT-matic preparations. This becomes evident when the values for mean increase in area of the canals, from pre-preparation to post-preparation, (Table 4) are analyzed. The canals prepared by conventional hand instrumentation display progressively larger values from apical to coronal portions. Values for the "MAC" prepared canals do indicate that the preparation becomes larger from apex to crown, yet, not to a significant degree. In addition, examination of the "MAC" prepared canals from the superimposed tracings, reveal preparations lacking any distinctive taper. The NT-matic prepared canals not only lack a significant coronal flare but actually become slightly larger in the middle portions of the canals, this phenomenon, however, is not as evident when the superimposed tracings were evaluated.

The fact that no significant differences were found in the apical portions of the canal between hand instrumentation and NT-matic instrumentation disputes the qualitative evaluation that increased elliptication of the canals occurred with conventional preparation. If this were so, significant differences for increase in apical area between the two methods would be expected. Therefore. it may be assumed that the NT-matic does not follow canal curvature to any greater degree than does hand instrumentation.

It would be difficult to speculate on the degree of cleansing or debridement that might be achieved, by the three preparation methods, from the results of this study. Also, no attempt was made to obturate any of the prepared canals, however, a #35 gutta percha cone was placed in several of the canals and generally could be advanced to full working length in all preparations. Whether or not further obturation might be possible, as in the addition of accessory cones followed by a spreader (the lateral condensation method), is unknown, but following both qualitative and quantitative analysis, it was assumed that in the "MAC" and NT-matic prepared canals this would be difficult. Even, Serene (39) in his report on the use of the "MAC" file at the University of South Carolina, suggested that filling methods other than lateral condensation would have to be employed if canals were to be prepared with the Nitinol file system.

In regard to any claims, suggesting that use of the Nitinol files make canal preparation easier or less tedious, differing observations were made. Instrumentation with the "MAC" files was far from effortless. Cutting ability was perceived as being extremely poor. Filing beyond a size #25 file was quite tedious and required repeated instrumentation with preceding files before the next larger size file could be used. Flaring, also, was quite difficult and often times, in order to achieve any flare the files had to be forced and turned in the canals. Serene's (39) report gave a very favorable impression of the students' experiences with the use of these files; a significant achievement mentioned was the ease of which canals could be instrumented up to large sizes using the "MAC" file. On the contrary, the experiences of this operator proved just the opposite.

The NT-matic handpiece, conversely, eventually became "user-friendly" - having a very good feel, but this did not occur until several practice canals were prepared. The appropriate amount of pressure to exert and the proper motion needed to advance the files into the canals developed with experience. Initially, because the files would so effortlessly advance into the canal, it was very easy to over-instrument or in this case, to break through the apical end of the canal and out the reservoir. Another phenomenon encountered was the tendency of the larger size files to screw or pull down into the canal, this possibility is mentioned in the manufacturers literature and can eventually be avoided by close control of the instrument. However, a warning should be offered that the use of this instrument, by an inexperienced operator on a human subject, may end in a disastrous result. This "screwing in" of the large size files occurred frequently with initial use of the NT-matic. Most often the file could be retrieved but not until it had advanced past the apex by several millimeters, at one point the file did become lodged in the canal and had to be separated to disengage it from the handpiece.

A greater appreciation for the importance of meticulous technique when instrumenting curved canals was achieved by the procedures followed in this study. Conventional hand instrumentation still produced the most acceptable preparations if well established conventions of endodontic therapy are applied, it was also the method with which this operator was most comfortable. Nonetheless, distortions of the original canal shape, most commonly, elliptication of the apex, could result. If particular attention to pre-curving of files, avoiding forcing of files and using copious irrigation was maintained, the occurrence of distortions was less common. The perceived ease with which the Nitinol file systems, especially the NT-matic, negotiated the canals might lead one to believe that, they certainly may be a more efficient system for use in endodontic treatment. However, results generated here suggest that the Nitinol systems would be better employed as an adjunct to conventional instrumenting procedures rather than use as the sole method in preparation. The extreme flexibility and the apparent smaller size of the Nitinol files lend themselves for use as an intermediate file when advancing to larger sizes.

CONCLUSIONS

Simulated curved canals were prepared with hand instrumentation using stainless steel files, a new Nitinol hand file and the NT-matic mechanical handpiece. Canals were prepared to a MAF of #35 and a FFL of #50. the following observations and conclusions were made:

1. Conventional hand instrumentation, generally, produced the most tapered and flared preparations. Strict adherence to the principles of curved canal preparation must be maintained to avoid the creation of ledges and zips.
2. The "MAC" file closely maintained original canal curvature, yet, preparations lacked any perceptible taper and appeared under-prepared.
3. The NT-matic handpiece easily negotiated the canal, resulting in a preparation with a moderate flare. However, mean values of the area for the middle portion of the canals indicated that the canals were slightly larger in the middle than in the coronal portions.
4. Significant differences in preparation size were observed between the apical portion of the "MAC" prepared canals and the other two methods.

5. No significant difference was found in the apical portion of the canals between conventional hand and NT-matic instrumentation.

6. The new Nitinol file systems, in and of themselves, have inevitable limitations. They may prove, however, to be a valuable adjunct to preparation of curved root canals.

REFERENCES

1. Weine FS. Endodontic therapy. 4th ed. St. Louis: CV Mosby, 1989.

2. Weine FS, Kelly RF, Lio PJ. The effect of preparation procedures on original canal shape and on apical foramen shape. J Endodon 1975;1:255-262.

3. Walton RE. Current concepts of canal preparation. Dent Clin North Am April 1992;36:309-325.

4. Phillips RW. Science of dental materials. 8th ed. Philadelphia: WB Saunders, 1982.

5. Ingle JI. A standardized endodontic technique utilizing newly designed instruments and filling materials. Oral Surg 1961;14:83-91.

6. Heuer MA. The biomechanics of endodontic therapy. Dent Clin North Am July 1963.

7. Haga CS. Microscopic measurements of root canal preparations following instrumentation. Northwest Univ Bull Dent Res Grad Study, Fall 1967.

8. Schilder H, Yee FS. Pathways of the pulp: canal debridement and disinfection. 3rd ed. St. Louis: CV Mosby, 1984;175-204.

9. Mullaney TP. Instrumentation of finely curved canals. Dent Clin North Am Oct 1979;23:579-581.

10. Allison DA, Weber CR, Walton RE. The influence of the method of canal preparation on the quality of apical and coronal obturation. J Endodon 1979;5:298-304.

11. Lim KC, Webber J. The effect of root canal preparation on the shape of the curved root canal. Int Endod J 1985;18:233-239.

12. Levy G, Abou-Rass M. Endodontic file design and dynamics in automated root canal preparation. AO 1990;83:68-72.

13. Frank AL. An evaluation of the Giromatic endodontic handpiece. Oral Surg 1967;24:419-421.

14. Harty FJ, Stock CJR. The Giromatic system compared with hand instrumentation in endodontics. Br Dent J 1974;137:239-244.

15. O'Connell DT, Brayton SM. Evaluation of root canal preparation with two automated endodontic handpieces. Oral Surg 1975;39:298-303.

16. Jungmann CL, Bucher JF. Effect of instrumentation on the shape of the root canal. J Endodon 1975;1:66-69.

17. Klayman SM, Brilliant JD. A comparison of the efficacy of serial preparation versus Giromatic preparation. J Endodon 1975;1:334-337.

18. Weine FS, Kelly RF, Bray KE. Effect of preparation with endodontic handpieces on original canal shape. J Endodon 1976;2:298-303.

19. Abou-Rass M, Jastrab RJ. The use of rotary instruments as auxiliary aids to root canal preparation of molars. J Endodon 1982;8:78-82.

20. Lehman JW, Gerstein H. An evaluation of a new mechanized endodontic device: the Endolift. Oral Surg 1982;53:417-423.

21. Spyropoulos S, Eldeeb ME, Messer HH. The effect of Giromatic files on the preparation shape of severely curved canals. Int Endod J 1987;20:133-142.

22. Goldman M, Sakurai E, Kronman J, Tenca JI. An in- vitro study of the path finding ability of a new automated handpiece. J Endodon 1987;13:429-433.

23. Ianno NR, Weine FS. Canal preparation using two mechanical handpieces: distortions, ledging, and potential solutions. Compend Contin Educ Dent 1986;10:100-105.

24. Craig RG, Peyton FA. Physical properties of carbon steel root canal files and reamers. Oral Surg 1962;15:213-226.

25. Craig RG, Peyton FA. Physical properties of stainless steel endodontic files and reamers. Oral Surg 1963;16:206-217.

26. Oliet S, Sorin SM. Torsional tester for root canal instruments. Oral Surg 1965;20:654-662.

27. Craig RG, McIlwain ED, Peyton FA. Bending and torsional properties of endodontic instruments. Oral Surg 1968;25:239-254.

28. Chernick LB, Jacobs JJ, Lautenschlager EP, Heuer MA. Torsional failure of endodontic files. J Endodon 1976;2:94-97.

29. Lautenschlager EP, Jacobs JJ, Marshall GW. Heuer MA. Brittle and ductile torsional failures of endodontics instruments. J Endodon 1977;3:175-178.

30. Lentine FN. A study of torsional and angular deflection of endodontic files and reamers. J Endodon 1979;5:181-191.

31. Felt RA, Moser JB, Heuer MA. Flute design of endodontic instruments: its influence on cutting efficiency. J Endodon. 1982;8:253-259

32. Roth WC, Gough RW, Grandich RA. A study of the strength of endodontic files: potential for torsional breakage and relative flexibility. J Endodon 1983;9:228-232.

33. Newman JG, Brantley WA, Gerstein H. A study of the cutting efficiency of seven brands of endodontic files in linear motion. J Endodon 1983;9:316-322.

34. Roulet JF. Dynamic fracture of conventional endodontic instruments versus experimental files. J Endodon 1983;9:12-16.

35. Krupp JD, Brantley WA, Gerstein H. An investigation of the torsional and bending properties of seven brands of endodontic files. J Endodon 1984;10:372-380.

36. Andreasen GF, Morrow RE. Laboratory and clinical analyses of nitinol wire. Am J Orthod 1978;73:142-151.

37. Lopez I, Goldberg J, Burstone CJ. Bending characteristics of nitinol wire. Am J orthod 1979;75:569-571

38. Walia H, Brantley WA, Gerstein H. An initial investigation of the bending and torsional properties of nitinol root canal files. J Endodon 1988;14:346-351.

39. Serene T. Nickel-titanium instruments and application. American Association of Endodontics annual session 1993; personal communication.

40. Lim KC, Webber J. The validity of simulated root canals for the investigation of the prepared root canal shape. Int Endod J 1985;240-246.

41. Spenst A, Kahn H. The use of a plastic block for teaching root canal instrumentation and obturation. J Endodon 1979;5:282-284.

42. LaTurno SAL, Corcoran JF, Ellison RL. An evaluation of a teaching aid in Endodontics. J Endodon 1984;10:507-511.

43. Eldeeb ME, Boraas JC. The effect of different files on the preparation shape of severely curved canals. Int Endod J 1985;18:1-7.

44. Alodeh MHA, Dummer PMH. A comparison of the ability of K-files and Hedstrom files to shape simulated root canals in resin blocks. Int Endod J 1989;22:226-235.

45. Schulz-Bongert U, Weine FS. Method for constructing standardized simulated root canals. J Dent Educ 1990;54:328-330.

46. Baumgartner JC, Martin H, Sabala CL, Strittmatter EJ, Wildey WL, Quigley NC. Histomorphometric comparison of canals prepared by four techniques. 1992;18:530-534.

APPROVAL SHEET

The thesis submitted by Dr. Mary Ann Ellenz Campbell has been read and approved by the following committee:

Dr. Franklin S. Weine, Director
Professor, Director, Graduate Endodontics, Loyola

Dr. Jerome V. Pisano
Assistant Professor, Graduate Endodontics, Loyola

Dr. James L. Sandrik
Professor and Chairman, Department of Dental Material, Loyola

The final copies have been examined by the director of the thesis and the signature which appears below verifies the fact that any necessary changes have been incorporated and that the thesis is now given final approval by the Committee with reference to content and form.

The thesis is therefore accepted in partial fulfillment of the requirements for the degree of Master of Science.

6-30-93
Date

Franklin S. Weine
Director's Signature